THE UNIVERSITY OF ALBERTA

SOME PHYSICAL FACTORS INFLUENCING MOISTURE DISPERSION AND STICKINESS OF BUTTER

A THESIS

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ABSTRACT

Homogenization in a Benz & Hilgers "Microfix" machine improved the moisture dispersion in both conventional and continuously made butters. Storage at 20°F before homogenization resulted in an increase in droplets in the 4 - 10 micron range and this increase was observed in the butter after homogenization. Storage at 40°F did not cause any change in droplet size. Moisture droplets were more finely divided when a fine rotor was used, as compared to a coarse rotor.

Passage of butter through the Kustner, B.M.R., and Richardson Success printing machines which operate on the Archimedean screw principle, caused a change in the butter structure, resulting in free moisture on the butter surface and loss of moisture from the butter. Butter printed with a Blanchet printing machine in which two polygonal rollers push the butter to the moulding compartment showed no free moisture, indicating that the structure of the butter was not disturbed to any marked degree.

Hesion measurements on commercial samples of conventional and continuously made butters showed that the hesion measurements were generally lower in the continuously made butter. This could be accounted for when we realize that the continuously made butters were generally harder than the conventional type of butter. This means that the apparent area of contact between the adherend and the butter surface was not as great in the hard butters as in

the soft butters, resulting in lower hesion values.

The results of hesion experiments carried out on conventional and Gold'n Flow types of butter made from the same cream indicated that the characteristic crystal structure of these types of butters influenced the hesion values. Homogenization of Gold'n Flow and conventional commercial butters increased hesion readings significantly. When nitrogen gas was added to pre-crystallized continuously made butter in varying amounts, the hesion values decreased with increasing gas content. However, there was an increase in the amount of butter which remained on the adherend when it became detached from the butter surface. Limited experiments on the effect of gas content in conventional butter indicated that an increase in gas content resulted in a decrease in hesion values with more butter remaining on the adherend.

The term "stickiness", as used in the butter industry, refers to that property of butter which allows it to remain attached to solid surfaces. It is a phenomenon in which the components of force caused by adhesion and cohesion are inseparably involved. The results of this investigation indicated that the crystal structure was responsible for the adhesive property of butter and the gas content influenced the cohesive property. It would appear, then, that both the crystal structure and the gas content play an important part in the cause of the "stickiness" defect in butter.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES AND PLATE

SOME PHYSICAL FACTORS INFLUENCING MOISTURE DISPERSION AND STICKINESS OF BUTTER

INTRODUCTION

Butter is graded according to its flavour, body and texture, colour, salt and the appearance of the package. The flavour of butter has received the most critical attention, but in recent years, considerable importance is being attached to the body and texture. Among the most common defects in body and texture are "leakiness" and "stickiness".

From the purely physical point of view, butter is basically an emulsion in which the continuous phase is the liquid component of the butterfat, and the disperse phase fat globules and water. In salted butter, the disperse phase is brine. In practice, the emulsion is not always perfectly formed and this results in some of the water not being completely dispersed within the fat. This condition may be observed as free moisture which appears on a freshly exposed surface of a piece of butter when cut. According to Prentice (1954), similar imperfections in the emulsion may arise even when the moisture is properly incorporated. If the membranes of fat surrounding the dispersed water are originally weak and are subsequently damaged through severe treatment, the water droplets coalesce resulting in butter with free moisture.

Factors known to influence the body and texture of butter

are the variations in the butterfat composition and in the manufacturing procedures. Variation in the chemical composition of milk fat is the main factor responsible for the seasonal differences in body and texture. Butter produced during the summer months is often too soft and melts down too easily. During the winter months, it is frequently too hard and lacks desirable spreadability. There is considerable literature on the temperature treatment of the cream as a means of influencing the body and texture of butter. The important factors probably involved are (1) the rate of cooling, (2) the temperature to which the cream is cooled and (3) the holding temperature.

It is well known that working of butter may influence its consistency. Two types of equipment in commercial use are designed for the mechanical treatment of butter. Treatment of butter in these machines, the Wernerizer, a vacuum-plasticising machine used in Australia and the Mikrofix , an homogenizer type of machine developed in Germany, results in butter with improved consistency and moisture distribution.

The introduction of continuous methods of butter making has resulted in the production of butters with a physical structure and consistency, different from that of conventional (churned) butter. It has been noticed that this type of butter lacks the inherent "stickiness" defect of conventional butter. In the present investigation, work was undertaken to try to determine some of the causes of this "stickiness" defect. Investigations were also carried out on the influence of mechanical treatment on moisture dispersion in butter.

REVIEW OF LITERATURE

Moisture Dispersion.

The dispersion of moisture in butter is very important to the keeping quality and appearance of the butter. On the matter of keeping quality, from a bacteriological standpoint, much work has been done by Long and Hammer (1938), Rahn and Boysen (1928) and other investigators. Hoecker and Hammer (1945) studied distribution of salt and moisture in butter with micro methods and their results led them to believe that (a) there was a correlation between salt distribution and moisture dispersion, (b) in samples of butter with abnormal flavours, moisture often was not as uniformly distributed as in thoroughly worked butter and (c) that in mottled butter, the light coloured portions usually contained less salt than the dark coloured portions.

With respect to appearance, Storch (1897), Sammis and Lee (1912) and Hunziker and Hosman (1920) have shown that unevenness of colour, such as mottles and waves, is a result of lack of uniformity of size and of distribution of the water droplets in butter. Salted butter when insufficiently and unevenly worked, invariably becomes mottled upon standing, because in such butter the fusion, dispersion and emulsification of brine and water are incomplete. Owing to the difference in concentration, water is attracted to the points of high salt concentration by osmosis. The resulting migration of water and brine droplets causes the loosely held droplets to coalesce, forming larger and fewer aggregates giving the portion of the butter where they are localized the

appearance of a more translucent and deeper yellow colour. The large number of small droplets with their countless surfaces and sharp curvatures do not permit the rays of light to penetrate the butter sufficiently to reveal the natural yellow colour of the butterfat. The rays are refracted and deflected, giving the butter an opaque whitish appearance.

Butter structure. In order to gain a better understanding of moisture dispersion in butter, whe should have some knowledge of the structure of the butter. Various theories have been put forward.

According to Fischer and Hooker (1916), an inversion of the phases takes place when butter is formed. In the finished product, the fat constitutes the continuous phase in which are dispersed the droplets of the aqueous phase. Rahn (1926) critized this, saying that fat is in a solid state in the cream before churning and also solid in the finished butter. He however agreed that the microscopic picture of butter proved that the fat phase is continuous. In his theory, he suggested that the fat is not a structureless mass in the butter, but that the original fat globules with protective protein are still recognizable. The fat globules collect in the foam formed during churning, and, as the process advances, they coalesce into small masses of butter or granules. The butter is then a mass of fat particles pressed together, still surrounded for the most part by their protein membranes and between which are imprisoned water droplets.

However, microscopic observations show that both the fat globules of butter and the moisture droplets are quite regularly

round. If one admits the continuity of the aqueous phase, this cannot be explained. There must exist some substance to fill the spaces between the fat globules and the water droplets. King (1955) interprets this to be the liquid fraction of the butterfat. This viewpoint was corroborated by the fact that butter can be "diluted" with the continuous phase - a liquid fraction of butterfat - and by the easy diffusion of fat soluble dye into the butter.

Moisture dispersion. Boysen (1927) was the first to establish some fundamental data on the dispersion of water droplets according to their size. He divided them into three groups - Group I consisting of droplets up to 15 microns in diameter; Group II between 15 microns and 100 microns and Group III over 100 microns. These droplets were counted with the aid of a microscope. He also studied changes in moisture dispersion brought about by salting and working and found that salting induced a large decrease of Group I droplets and an increase in Group III. Group II remained the same. However, working the butter produced an increase in the degree of dispersion of moisture, the number of droplets in Group III decreasing and Group I increasing.

Theory of the working of butter. Butter tends to flow when kneaded. Some moisture drops collide and coalesce, while others are elongated and dispersed into smaller drops. This flowing that occurs as a consequence of working is highly irregular and very complicated. Particles of butter are connected to each other through the interlacing of fat crystals, structures of a thixotropic character, and by water containing surfaces of fat globules. According to Mulder and Den Braver (1956a), the dimensions of the moisture droplets are of greater

importance for coalescence than their numbers. The larger the drops, the greater the chance of coalescence. The number of collisions of moisture drops is greater with a higher gradient of velocity. Therefore more droplets come into collision with each other and the chance of coalescence is greater when the butter is worked more vigorously. However, according to Mulder and Den Braver, not every collision is followed by coalescence. The force with which droplets collide depends on the viscosity of the butter. When the butter is soft, coalescence of the droplets does not take place. The boundary tension between a droplet and the surrounding medium is of much importance because there is a decrease in boundary energy with coalescence. Smaller droplets are more difficult to deform than larger droplets as a consequence of surface tension. The greatest hindrance to coalescence of the droplets is the force which resists disruption of the droplets. This force determines whether coalescence is possible or not. Deformation and disruption of drops are influenced by:

(1) The size of the drops.

(2) The gradient of velocity.

(3) The viscosity of the dispersion.

Therefore large dimension of drops, high velocity of gradient and high viscosity favour bursting of the droplets (Mulder and Den Braver).

Coalescence and rupture of water drops occur at the same time when butter is worked. Circumstances determine which process predominates. The size of droplets which occur in greatest numbers after working will depend on the number and size of the drops before working

and the intensity of working. When the working is vigorous, the droplet sizes are small and the butter is dry, while with gentle working, a high proportion of large drops and consequently leaky butter are obtained (Mulder & Den Braver).

Working of butter. The objectives of working butter are:

(1) To unite the butter granules into a homogenous mass for convenient handling and packing.

(2) To bring the moisture content to the desired level.

(3) To dissolve completely, distribute uniformly and properly incorporate the salt into the butter.

(4) To divide the moisture drops into smaller drops of such a size that they are completely incorporated.

(5) To help in the expulsion of buttermilk.

Working is accomplished in churns with or without rollers. In churns without rollers, the working effect is determined by the impact of the falling butter, whereas with roller churns, the speed of the rollers determines the working effect. In perforated plate workers, the butter is forced through a series of perforated plates. The compartments between the plates often contain multiblade beaters. The butter is then worked in two ways:-

(a) by the beaters

(b) by the plates.

The kneading action of the beaters is similar to the working by rollers. When the butter is forced through perforated plates, the gradient of velocity is higher when a greater quantity of butter is being forced

through the orifices in unit time. The butter can be worked more readily with a plate having a large number of openings than with one containing a few large openings of the same total surface area, because butter shows a great tendency to "plugflowing" and a higher velocity gradient will occur near the walls of the orifice (Mulder & Den Braver, 1956b). This means that the butter is worked at the periphery and not in the centre of the "plug", so that the greater the number of openings, the greater will be the amount of working.

During recent years, homogenizers have been used, especially when cold stored butter is moulded into prints. Similar processes have been used in the margarine industry for many years. However, only firm butter is suitable for the rough treatment that the butter undergoes.

Since 1954, with the development of the Kronberg homogenizer, patented by N.A. Sorensen and produced by P. Andersens, Efterfolger, Copenhagen, there has been a renewed interest in the use of homogenizers. The homogenizer was intended only to give freshly produced butter an afterworking which caused a distribution of smaller water droplets. Later on, the machine was strengthened considerably to permit the processing of cold stored butter.

The homogenizer operates in such a way that the butter is carried along by two Archimedean screws to the working device. The working device consists of a rotor which is in a horizontal cylindrical rotor-housing and which rotates around its axis.

The working intensity of the homogenizer can be regulated by

varying the speed of rotation of the screws, insertion of the whole or half grate at one of the openings of the rotor-housing and by an adjustable shut-off of the outlet spout of the homogenizer.

In 1956, Benz and Hilgers designed the Microfix after the same principle as the Kronberg homogenizer. The working intensity of this equipment is controlled by inserting rotors having 16, 24 and 30 blades and also by adjusting the size of the outlet.

Pedersen (1960) is the first investigator to attempt an explanation of the principles involved in butter homogenization. He states that homogenizers constructed according to the rotor principle cut the butter into paper-thin slices and subsequently work them together again. This removal of a paper-thin slice over the entire surface of the column of butter being forced into the rotor head is reported to produce the first subdivision of the moisture droplets. The second subdivision takes place as the rotor turns and the thin slice is deposited on the surface of the outgoing butter. This clearance between rotor and rotor-housing is 1 mm which limits the thickness of the slice that is removed and redeposited by the rotor.

A number of workers in Europe, Dibbern and Koenen (1956, 1957, 1959), Koenen (1958, 1959), Mohr _et al_. (1958a, b), Mohr and Oldenburg (1959), Pedersen (1960) and Petersen (1960), have studied the influence of homogenization on the properties of different types of butter. Dibbern and Koenen (1956, 1957), Mohr _et al_. (1958a), Pedersen (1960) and Petersen (1960) found that homogenization of cold stored conventional butter decreased hardness and improved moisture distribution, while Mohr _et al_. (1958b) and Pedersen (1960) found

that homogenization of freshly churned butter improved moisture distribution, but had very little effect on reduction of hardness. Fisker (1958) and Petersen (1960) are of the opinion that homogenization may injure the keeping quality of butter by rendering it more susceptible to oxidation, since the surfaces between water and fat are increased.

Printers. Butter is liable to become leaky when it is passed through printing machines. The kneading action is such that the shearing forces are low and consequently flowing together of the moisture droplets takes place. The large drops of water formed are loosely held and easily pressed from the butter, causing excessive loss of weight. Mulder and Den Braver (1956b) stated that the deforming forces acting on droplets are the same as the shearing force which makes butter flow. This force is expressed by $k = \eta \frac{dv}{dx}$ in which η = viscosity of the butter and $\frac{dv}{dx}$ = gradient of velocity. Because of surface tension, the droplets try to keep a spherical form. This force has to be overcome before the droplets can be extended. The value of this force is $p = \frac{2\gamma}{r}$ where γ = surface tension and r = radius of the droplet. For deformation of the droplet to take place, the shearing force must be greater than the force trying to maintain the droplet spherical.

$$\eta \frac{dv}{dx} > \frac{2\gamma}{r}$$

The droplet must then be disrupted. Mulder and Den Braver (1956a)

stated that large drops, high gradient of velocity and high viscosity favour bursting of the droplets. Therefore, the gentle working which butter receives in most printers encourages the formation of large droplets and leaky butter.

Thomé (1953) showed that if butter is stored in bulk and is worked in a printing machine after thawing, a coarsening of the water dispersion inevitably occurs independently of how the butter is made.

According to Thomé and Samuelsson (1956), when butter is stored between manufacture and printing for such a period as allows it to set, there is a distinct fall in quality after printing. They observed that the deterioration was the same whether the butter was stored at 5°C or 15°C. They suggested that reworking before printing could counteract this fall to a high degree. The butterfat crystals keep the water phase dispersed. The smaller the crystals, the more complete is the dispersion. The coarsening of moisture droplets is probably caused by the growth of the crystals and the weakening of the emulsion when butter is stored and the change of structure in the butter when it is reworked in the printer. Mohr and Mohr (1954), using freshly made summer butter, found that printing immediately after working did not affect the droplet size dispersion, whereas storage for 24 hours at 6° - 8°C before printing increased it still more.

Stickiness.

Stout (1938) stated that stickiness is associated with the working of butter, in which excessive fat crystallization has caused a shortage of liquid fat. He pointed out that in the working of

butter, liquid fat is needed for lubrication and since there is a shortage of liquid fat, the fat globules are bruised and torn in the working process, resulting in the sticky character of the butter.

Several workers have drawn attention to varying degrees of stickiness and these are generally attributed to variations in the butterfat composition and the processing treatments applied to the butterfat. Hunziker (1940) stated that stickiness may be produced at any time of the year by overworking soft butter, especially when free moisture is not present. He said that if the character of the cream is favourable towards stickiness, overworking of the butter will intensify the defect.

Many investigators stated that stickiness was more common during the winter months when cows were not fed on pasture. Wilster et al. (1941) found the defect more common in butter made in areas where cows were fed large quantities of alfalfa hay. According to these investigators, the milk fat obtained when certain dry feeds, particularly hay, were fed, contained a low percentage of low melting point glycerides and a high percentage of high melting point glycerides. These factors resulted in a firmer bodied butter sometimes showing either crumbliness or stickiness, or both. It appears that during the fall and winter when cows are not on pasture, the butterfat shows a low Iodine number, high melting point, low Reichert Meissl number and a low refractive index. Wilster et al. stated that stickiness was apparent when the unsaturated and volatile fatty acid content in the fat was low. They found that the significant

difference between butter with a satisfactory body and texture and butter that was sticky and crumbly, was caused by a difference in the Reichert Meissl and Polinski numbers.

Small changes in the percentage of different glycerides in fat apparently affect the texture and consistency of the butter. The feed of cows has a pronounced influence on the chemical make-up of the butterfat. It is possible, then, that the composition of the feed that is fed to the cows is one of the factors involved in stickiness.

On the other hand, it has been shown that manufacturing methods may contribute to the stickiness defect. Richardson and Abbott (1935) have reported that it is possible to improve the body of sticky butter by controlling the manufacturing process. Zottola et al. (1961) noted that it was possible to manufacture butter with excellent physical properties, using a cream-temperature treatment with the Iodine value and melting point value indicated relatively hard fat. With this treatment, the cream was cooled to 46°F after pasteurization, held at this temperature for two hours, slowly heated to 66°F, and held at this temperature for six hours. The cream was then cooled to 61°F, held overnight (fifteen hours) and churned the next morning at a temperature of 47°-48°F.

According to Mulder (1949), the physical structure of butter is influenced by the following factors:-

(I) The structure of the materials from which the butter is prepared.

(2) The method by which the butter is made.

(3) The treatment of the butter after its preparation.

Five years of investigation on the problem of crumbliness, stickiness and excessive hardness, causing poor spreading and printing properties, resulted in a modified churning procedure for winter butter called the "50-45-40" Method (Wilster et al., 1942). Briefly, this method consisted of cooling the cream slowly after pasteurization to 50° F and holding it overnight at this temperature, using wash water at a temperature not higher than 45° F and storing the butter manufactured, at a temperature of 40° F. When this method was used, the butter was soft and waxy.

There was no c oncerted effort to measure stickiness objectively until Claassen s (1958) began his investigations. He developed the "Hesion B alance" with which he measured the hesion of butter to different materials in terms of the vertical pull necessary to detach an adherend of the material in question from the butter after a given contact time. Claassens used the term "hesion" in preference to "stickiness", since in measuring the phenomenon by the above method, the components of force as a consequence of adhesion and cohesion are inseparably involved. The "Hesion Balance" used was a modified Westphal specific density balance. A macrotome (Claassens, 1957) was designed for preparing a smooth surface on the butter sample so that the best possible contact with the adherend was achieved. The adherend was suspended from one end of the beam and counterpoised by a vessel containing mercury. The butter surface was brought into contact with the adherend for a given time.

Pull on the adherend was provided by running mercury from a burette into the vessel until the adherend was detached. From the apparent area of contact, the volume and density of the mercury at the temperature of the experiment and the gravitational pull, the hesion or retaining force was calculated.

Claassens (1959a) was able to show that the measurable hesion between butter and various adherend materials is dependent upon (1) the time of contact, (2) the nominal load, (3) the temperature of the butter and (4) the physico-chemical nature of the adherend surface. The method proved to be sufficiently sensitive to distinguish between butters of varying degrees of "stickiness". Claassens reported that when the adherend became detached, the break occurred below the contact interface, i.e., in the structure of the butter. Under identical conditions of load, temperature and contact time, the amount and appearance of butter on the detached adherend surface differed extensively from portion to portion within the same test surface. This variation could be ascribed to the heterogeneity of the structure of the butter. According to Claassens (1959c), if the cohesive strength of the butter is small compared to the interfacial adhesion, the measurable hesion will be small, but if both adhesive and cohesive forces are large, hesion values will be high.

Claassens (1959b) designed a tilting platform to provide additional information on stickiness in butter. The purpose of the apparatus was to investigate the "apparent" coefficient of static friction of butter against metal and other hard surfaces. According

to Bowden (1957), "there is a close relationship between friction and adhesion. Friction is essentially the sheer strength, and adhesion the tensile strength of the junctions formed at the region of contact." Claassens (1959c) found that there was a significant positive correlation in commercial butters which did not vary greatly in composition, between the coefficient of static friction and hesion values. He found that greatest hesion occurred in blended butters, followed by straight reworked and straight unreworked butters.

Jansen (1961) found that Claassens' Hesion Balance was not suitable for examining large numbers of samples. He designed an apparatus consisting of a platform on which the butter sample is clamped, which is retracted through suitable gearing by an electric motor. The adherend resting on the sample hangs on a cord passing over and attached to a pulley. A counterpoise passing through the arc of a circle is attached to the pulley. The pointer on the pulley is constructed as a lazy hand and remains in position over a scale when the adherend becomes detached. The scale is calibrated to give hesion in grams.

Jansen examined samples of butter for hesion, extruder thrust, extruder friction and liquid fat index and found that the correlation between hesion and the three other properties was dependent on temperature. He also compared hesion of butter with the standard deviation in weight of the packets when the butter was printed, but his results showed no significant influence of hesion on the accuracy

of operation of the printing machine. He stated that repeated working of butter in a laboratory scale butter blender showed an increase in hesion after the first working and a decrease after each of six further workings. Jansen noted that an increasing amount of butter adhered to the adherend after each working.

EXPERIMENTAL PROCEDURE

SAMPLES

Moisture Dispersion Experiments.

Homogenization. A Benhil[1] butter homogenizer, Model Microfix, was used for the homogenization of the butters. Hereafter butter processed with this equipment will be referred to as homogenized. The machine consists of a pair of augers propelling the butter to the homogenizing head. The head was fitted with fixed speed interchangeable fine and coarse rotors with 30 and 16 blades respectively. The augers turned at 18 r.p.m. The restrictor or back pressure plate, which regulates the flow from the machine and consequently has some influence on the intensity of the homogenizing treatment, was maintained at a half open setting.

Conventional and Gold'n Flow[2] (continuously made) types of butters obtained from Edmonton creameries were homogenized separately in lots of 150 to 300 pounds. Each lot of butter was stored in tempering rooms of 20° F and 40° F ± 1° F for at least one week before homogenization, in order to bring the butter to a relatively constant temperature throughout. One pound size print samples were taken after the machine had attained normal operating conditions. These

1 Made by the firm of Benz and Hilgers, Dusseldorf Nord, West Germany.

2 Made by a process known as Gold'n Flow, which is copyrighted by the Cherry-Burrell Corp., Cedar Rapids, Iowa.

samples and samples obtained before homogenization were stored at 40°F until examined to determine moisture dispersion.

<u>Printing</u>. Butter samples from four different types of printers were obtained. Three of the printers were situated in Edmonton creameries and the fourth was located in Red Deer. The four types of printers under observation were Blanchet, B.M.R., Kustner and Richardson "Success".

The Blanchet is a printing machine especially designed for the handling of soft butter. The butter placed in the hopper is carried vertically downwards to the moulding section by two rotating polygonal rolls, 12 ins. in diameter. The weight of the butter itself is thus used to assist in the feeding of the moulding section of the machine. The texture of the butter is hardly disturbed by the rollers.

The B.M.R. and Kustner printers are automatic type moulding and wrapping machines, while the Richardson "Success" printer is a simple form of manually operated butter extruder. All three employ the principle of a pair of augers which rotate to force the butter into a mould. The working that the butter receives with the aid of the augers causes a disruption in the texture of the butter.

Samples of butter were obtained from these printers both before and after printing. The "Indicator Paper Method" was applied immediately and the butters were examined under a microscope at the laboratory. This method is described elsewhere.

<u>Hesion Experiments</u>.

<u>Laboratory continuous buttermaking machine</u>. Conventional butter

was obtained from an Edmonton creamery and after samples were taken out for later measurements, the remainder (approx. 30 lbs) was melted down to be used as the butterfat concentrate in the laboratory continuous buttermaking machine (Flow diagram Figure 1). The temperature of the butterfat concentrate was maintained in the range of 100° to 105°F in the mixing tank A which was equipped with an electric heater and a motor driven stirrer. The concentrate was pumped through line a to b by pump E_1 to the precrystallizer C. When C was filled, the concentrate was forced through cd to the chilling unit B. The chilled concentrate then passed through ef to D, the texturator, where crystallization occurred. The butter was then worked by its passage through the texturator plate g. Pressure was built up in the machine because of the passage of butter through the texturator plate and the tapered outlet. Gear pump E_2 circulated a portion of the chilled butter through the branch line hk to the precrystallizer C. This chilled butter was thoroughly mixed with the incoming warm concentrate entering via line ab. The first butter emerging from D, the texturator, was reprocessed, since it had not been precrystallized.

In some experiments, nitrogen gas was added in varying amounts to the butter. At junction H of c and m, a bent hypodermic needle soldered into a tee permitted the gas from the nitrogen cylinder and chilled butter concentrate from the precrystallizer to mix in d before entering the crystallizer B.

When non-precrystallized butter was manufactured, line b was removed and replaced by a direct line from E_1 to B.

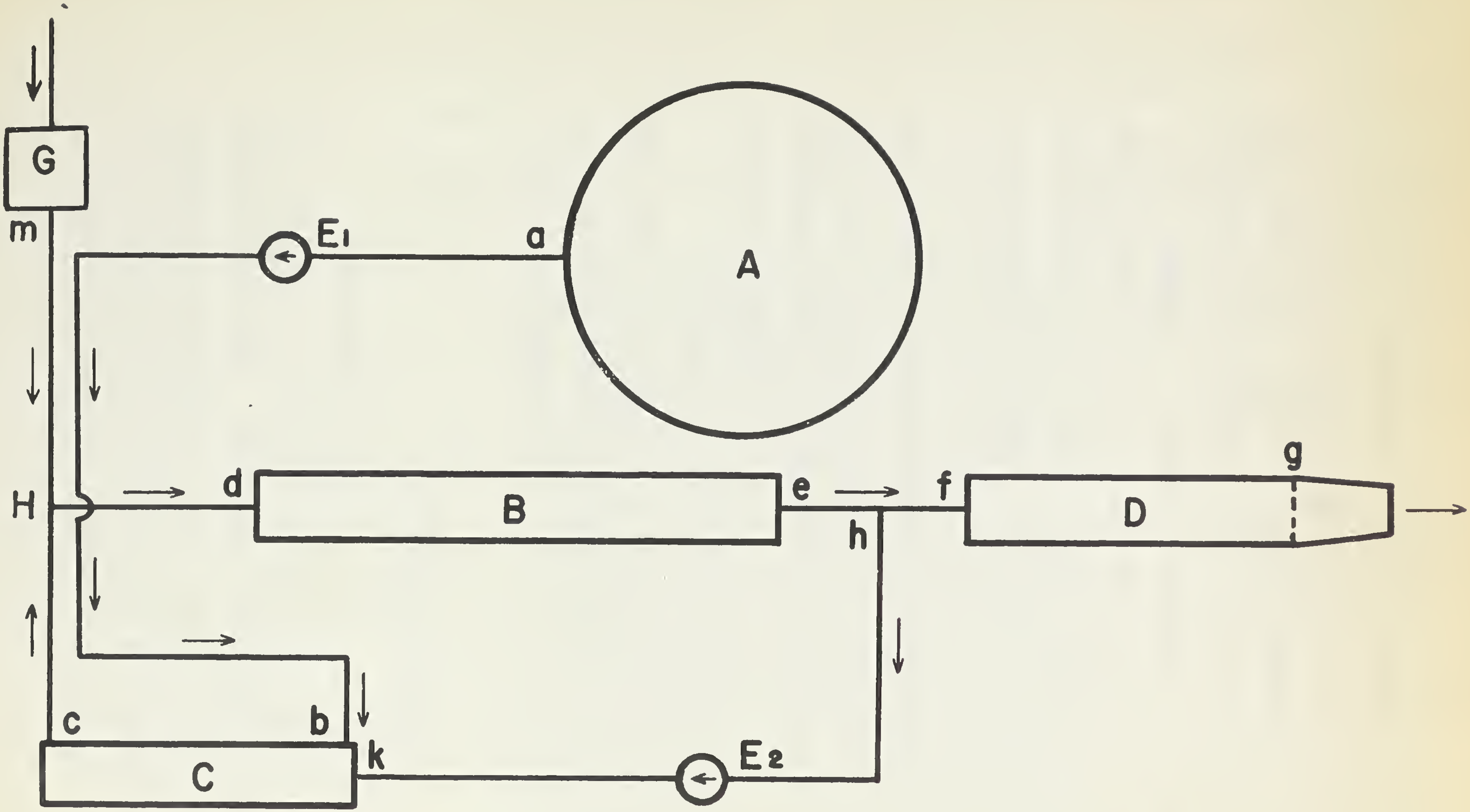

Fig. 1. Flow diagram of the laboratory continuous buttermaking machine with precrystallizing unit and gas flow meter.

A - mixing tank; B - chiller; C - precrystallizer;
D - texturator; E_1 E_2 - pumps; G - gas flow meter.

The butter obtained from this machine was extruded directly into cylindrical stainless steel frames to be described elsewhere and stored at 40°F for 1 week before measurements were made. The temperature of the extruded butter was in the range of 42° - 47°F.

Blender. Samples of conventional and continuously made butter manufactured in the laboratory continuous buttermaking machine were reworked in the laboratory type blender or Wernerizer without the application of vacuum. Some samples of conventional butter granules taken from churnings of butter after the draining of the buttermilk were worked with the application of vacuum of -.8 Kg/cm. The blender (Figure 2) consists of a strong metal vessel with semi-cylindrical bottom, into which are fitted two sigmoid shaped beaters which are reversible.

The butters were worked for varying lengths of time and then samples were moulded into cylindrical stainless steel frames to be described elsewhere. These frames were stored at 40°F for 1 week before examination.

INDICATOR PAPER METHOD

Representative samples of butter before and after printing were subjected to the indicator paper test introduced by Knudsen and Sorensen (1938). Filter paper containing bromophenol blue indicator, when placed on a cut surface of butter for 30 seconds, turns blue when water droplets are absorbed by the paper. A piece of "Presto" indicator paper obtained from the Chas. Hansen

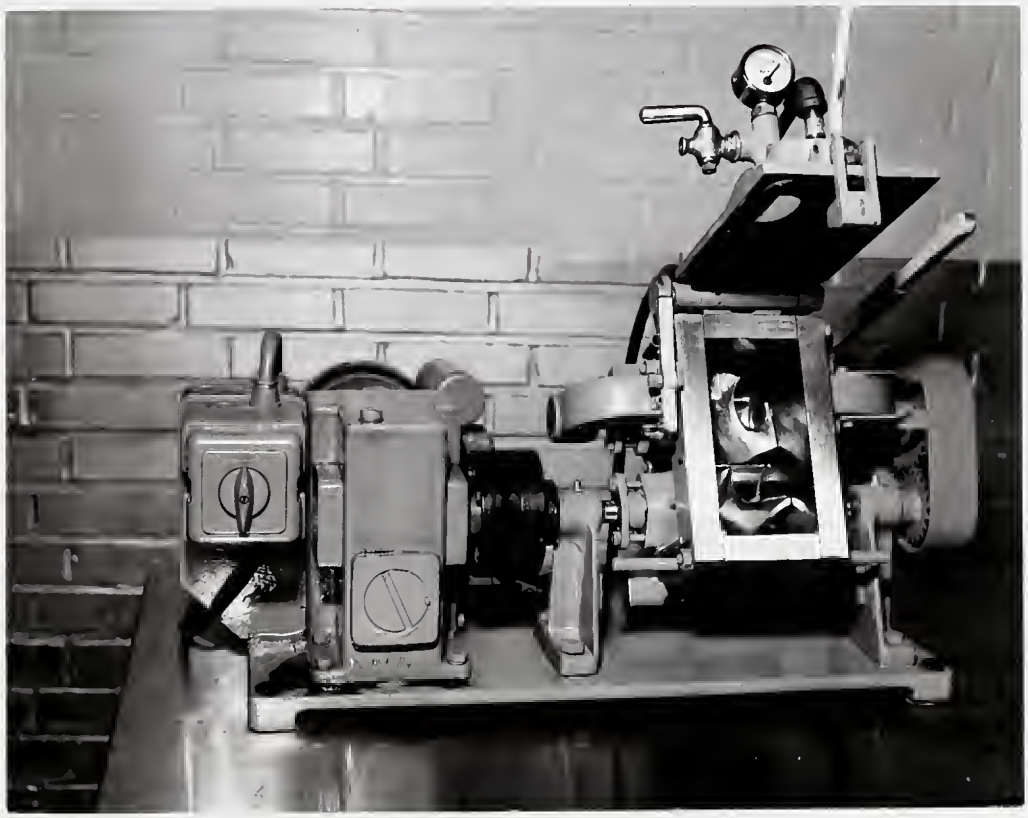

Fig. 2. Laboratory type blender for reworking butter.

Laboratories, Copenhagen, Denmark, was placed on a freshly cut smooth surface of butter. The paper was rubbed lightly (without moving it) to ensure perfect contact with the butter. The degree of moisture incorporation was judged with the aid of a standard chart by the size of the spots on the paper, when it was removed from the butter after 30 seconds.

DIRECT MICROSCOPY

Since it was desirable that information should be obtained not only on the size of the moisture droplets, but also on their numbers, a method devised by Herb et al. (1956) was employed which made it possible to examine layers of butter of definite and known thickness. The butter was warmed at room temperature for a few minutes. A definite amount of butter was weighed on a slide and with the use of a glass coverslip of 22 mm diameter and 380 mm^2 surface area, the butter was gently and evenly spread over the area of the coverslip.

The moisture droplets were placed in five groups, viz., droplets in the range 0 - 4 μ, 4 - 10 μ, 10 - 20 μ, 20-30μ and over 30 μ in diameter. The microscope used in this study was a Spencer which was fitted with a carbon light source attachment which enabled the microscopic image to be projected with the aid of a prism placed on the occular, on to a ground glass screen. This was done in order to decrease eye strain when counting the droplets. When the binocular tube was raised to 170 mm, the side of the grid in the eye piece

measured 100 μ when checked against a stage micrometer. The grid was divided into 100 squares, each square of length 10 μ. Magnification was 950 x. Two slides, each of sample thickness 5 μ, 10 μ, and 30 μ were used for each butter sample. Four fields in each slide were counted. Droplets in the first group, i.e., 0 - 4 μ, were counted in 10 squares of the grid, averaged and multiplied by a factor of 100. All other droplets were counted in 100 squares. The results are expressed as the percentage of the total volume occupied by the droplets of each group.

To test the accuracy of the method, five slides were taken from a sample of butter and ten fields were counted. The average number of droplets in the different groups compared favourably with counts made by the method described above (Table 1).

HESION

Macrotome for preparing smooth and flat surfaces in butter.

The macrotome (Figure 3) used was a modification of that designed by Claassens (1957). A platform was designed to carry a half pound print of butter. A centrally mounted screw-jack is used to lower or raise the platform in relation to the upper surface of two rails directly above it. A screw keeps the platform in position at any one setting. A cutting mechanism slides over the rails. Since the platform moves vertically and is always parallel to the rails at any given elevation of the platform, the vertical distance is the same between any given point on its surface and the upper surface of the

Table 1. A comparison of the average droplet counts in 8 fields on 2 slides and 50 fields on 5 slides in conventional and Gold'n Flow types of butter, using the direct microscopic count method.

		Droplet Range in microns				
Butter Type	No. of Slides	0 - 4	> 4 - 10	> 10 - 20	> 20 - 30	> 30
Conventional	2	1965	30	3	2	-
	5	1782	32	2	1	1
Gold'n Flow	2	5087	10	1	-	-
	5	4896	12	2	-	-

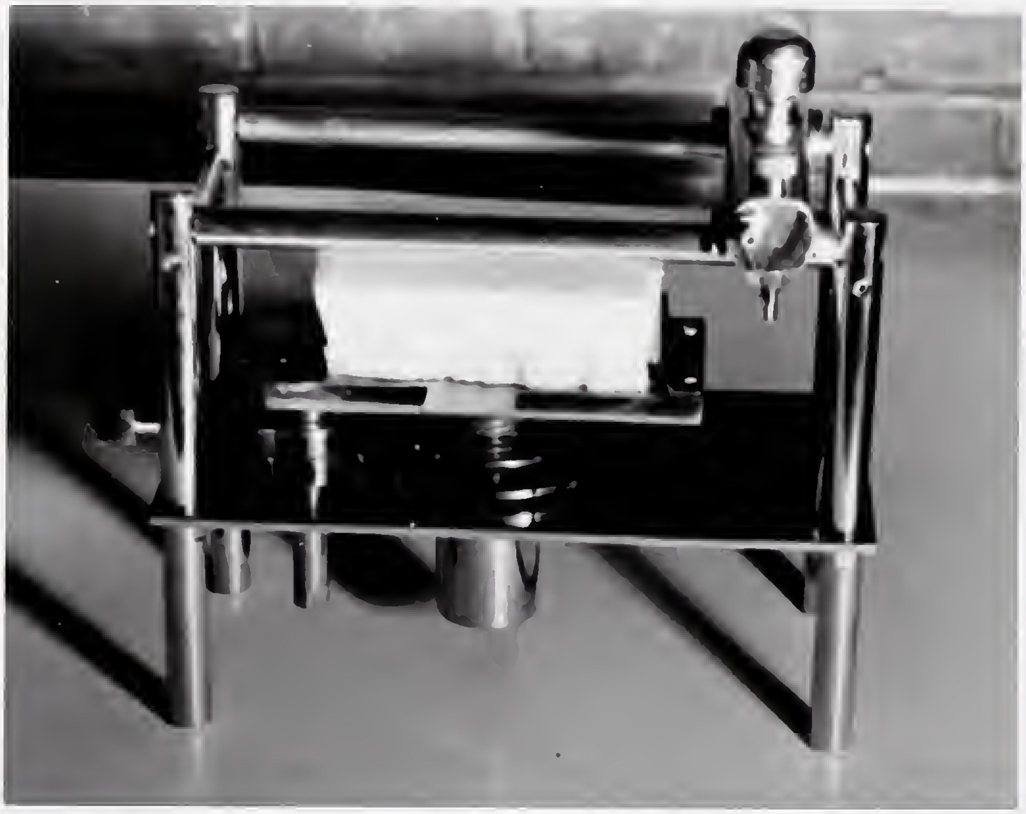

Fig. 3. Macrotome for preparing smooth and flat surfaces in butter.

Fig. 4. Apparatus for measuring hesion of butter.

rails. The wire in the cutting mechanism is a fixed distance below the rails. The degree of smoothness of the rails determines the evenness of the butter surface, while the wire passes through the butter and over the surface which is to be exposed for experiment. The butter prints were prepared in the manner described by Claassens (1957). The entire instrument was made of stainless steel.

Apparatus for measuring hesion.

An apparatus (Figure 4), similar in principle to that described by Jansen (1961), was constructed from a constant speed drive motor. The butter sample is clamped on to the platform of the lift, which is raised or lowered by suitable gearing of the electric motor. The adherend of stainless steel is cylindrical in shape and conforms to the specifications of Claassens (1958). Its lower portion has a diameter of 11.3 mm and is 10 mm high. The centrally turned spindle measures 30 mm in length and 4 mm in diameter. The unit weighs 11.5 g. A hollowed lead cylinder is placed around the spindle so that the total weight of the unit is 35 g. The adherend hangs on a nylon thread passing over a pulley to which is attached a counterpoise. The pointer which is attached to an adjacent pulley is constructed as a lazy hand and remains in position over the scale when the adherend becomes detached and the counterweight returns to its lowest position. The scale is calibrated to give hesion in grams. A test of the apparatus showed a sensitivity of ± 2.0 g. The apparatus was placed on a level surface and the platform was levelled before

Table 2. Comparison of hesion measurements (g) on $\frac{1}{2}$ lb. prints and cylindrical frames in conventional and continuously made butter.

Butter Types	Trials	Print	Frame
Conventional	1	96.7	90.0
	2	125.2	132.5
Continuously made	1	62.5	70.3
	2	58.6	54.9

Average of 45 measurements.

Average of 30 measurements.

measuring began. The contact surface of the adherend before measuring commenced, and between measurements, was cleaned by repeated washing in acetone and carbon tetrachloride and wiped with clean cotton wool. Measurements were made at a temperature of 50°F and the contact time was 60 sec.

When measurements were made on half-pound butter prints, 15 positions on each of 3 surfaces were measured. Measurements of butter in the cylindrical frames were made on 5 positions on each of 3 surfaces in duplicate samples. Hesion measurements on prints and frames compared favourably when made on samples from the same butter. (Table 2).

POLARIZED LIGHT MICROSCOPY

The technique developed by Herb *et al*. (1956) was employed in order to examine the crystal structure of the butters. A dilution method was adopted which gave the added advantage of more detailed pictures. A definite quantity of butter was weighed on a slide. The weight of sample was calculated so that it would form a layer 10 µ thick when spread evenly over the area occupied by a round cover glass of 22 mm diameter. An equal quantity of light mineral oil was then added to the same slide and the two substances mixed carefully and thoroughly with a small spatula. The slide was weighed again and the weight of the sample was reduced to half by removing the excess with a spatula. When covered with the round cover glass and spread evenly with slight pressure to fill the area under the cover glass, the sample represented a layer 10 µ thick, half butter and half mineral oil.

The microscope used in this study was a Zeiss-Winkel standard polarizing microscope which has the illuminator built into the base. The photomicrographs were made with the Zeiss-Winkel attachment camera and focussing eyepiece.

HARDNESS

All butter samples were measured at 62°F by the method of Kruisheer & den Herder (1938) as modified by Wood & de Man (1956) to permit tempering the samples in a constant temperature bath. Butter from the laboratory continuous buttermaking machine was extruded directly into tubular stainless steel frames 2.9 cm. in length and 2" O.D. Samples of conventional butter were pressed into these frames. The butter samples were kept in the frames in a cold storage room at 40°F for one week and then tempered in a 62°F water bath for 24 hours before testing. The water bath temperature was maintained thermostatically within ± 1°F. All hardness measurements were made immediately after removal of samples from the water bath, in a room maintained at 40°F ± 1°F. The modified instrument was calibrated with a balance and the gauge readings were converted to $Kg/4cm^2$ with the aid of a calibration curve. All hardness measurements reported are the average of two determinations.

GAS CONTENT

Gas content was measured by the direct method used by de Man & Wood (1958a). In this method the escaping gas, which was liberated from the butter by melting, was collected under water in

a graduated tube.

The apparatus for measuring the gas content consisted of hollowed brass frustra 44 mm in height with small and large diameters 22 mm and 28 mm respectively and with a capacity of approximately 20 g of butter. Glass funnels (dia. 7 cm) with stems cut to a length of 1 cm., graduated tubes made from 5 ml. measuring pipettes sealed at one end and rubber connections comprise the remainder of the apparatus. The funnels, with the graduated tubes disconnected, were immersed in 1-litre beakers filled with water. Air was expelled by boiling. The beakers and their contents were cooled to room temperature after expulsion of the air. Without being removed from the water, the water-filled tubes were fitted to the stems of the inverted funnels. To prevent excessive foaming, a few drops of sodium hexadecylsulfate were added. The brass frustra were pressed into the butter samples which had been tempered at 59°F. The ends were trimmed and the outside of the frustra carefully wiped clean. They were then immersed in the beakers under the funnels with the aid of forceps. The beakers were then heated to 112°F and the collected gas in the tubes was read after having been cooled to room temperature. The volume of gas was converted to standard pressure and expressed as a percentage.

OILING-OFF

The method used was similar to that described by Mohr & Baur (1948). A special forming device with an internal square

cross-section of 2.5 cm. fabricated by de Man and Wood (1958b) was forced into the butter to be tested. The plug of butter withdrawn by this trier was pushed out by a closely fitting plunger with a graduated stem and the butter plug was cut off at 2.5 cm length with a wire butter cutter. This operation was performed in a room where the temperature was maintained at 40°F.

The butter cubes were placed on piles of ten Whatman No.1 filter paper circles of 12.5 cm diameter and of known weight. The papers and cubes were weighed and stored at 77°F for 48 hours and the cubes then removed. To serve as a control, a similar pile of filter papers without a butter cube was stored under the same conditions. After removal from storage, the filter papers, both with and without the absorbed oil, were held in a dry atmosphere until the control returned to its original weight. The piles with the absorbed oil were then weighed. Oiling-off is expressed as the increase in weight of the filter papers in terms of percentage of the weight of the original butter cubes.

RESULTS

Influence of Homogenization on Moisture Dispersion.

The results obtained of representative churnings of conventional and continuously made butters stored and homogenized at 20°F and 40°F are shown in Figures 5, 6, 7 and 8. There was a marked increase in the volume of counted droplets in the size range 0 - 10 µ after homogenization and a decided decrease in the range over 10 µ. Statistical analysis (Table 3) shows that there was a significant difference ($P \doteq .01$) in the volume of droplets in the 0 - 4 µ range because of the homogenization treatment. In the 4 - 10 µ range, (Table 4) the significant difference in the volume of counted droplets between homogenized and non-homogenized butter is a result of both homogenization and the storage temperature before homogenization. Figures 5, 6, 7 and 8 show that when the butter was stored at 20°F before homogenization, there was a larger volume of droplets in the 4 - 10 µ range than when the butter was stored at 40°F.

The results in Figures 5, 6, 7 and 8 are expressed as the percentage of the total volume occupied by the droplets of each group. Reporting of droplets as a percentage of the total number of droplets would overemphasize those in the lower size range.

Photomicrographs of samples of conventional and continuously made butters (Figures 9, 10, 11, 12) present further evidence that there was a reduction in the moisture droplet size as a consequence of homogenization. This was the case in butters stored at 20°F and 40°F.

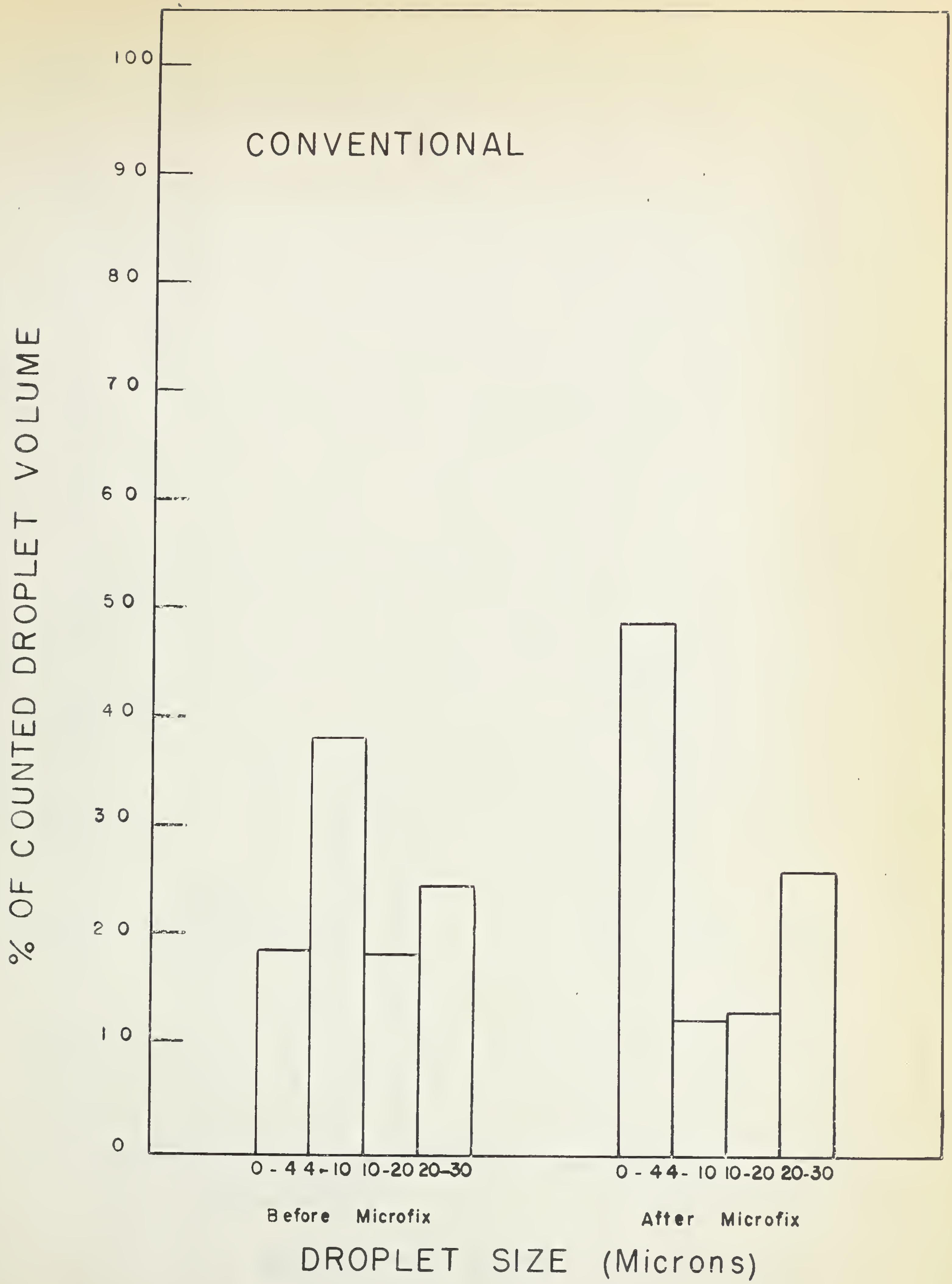

Fig. 5. Influence of homogenization on moisture dispersion in conventional butter stored at 20 F.

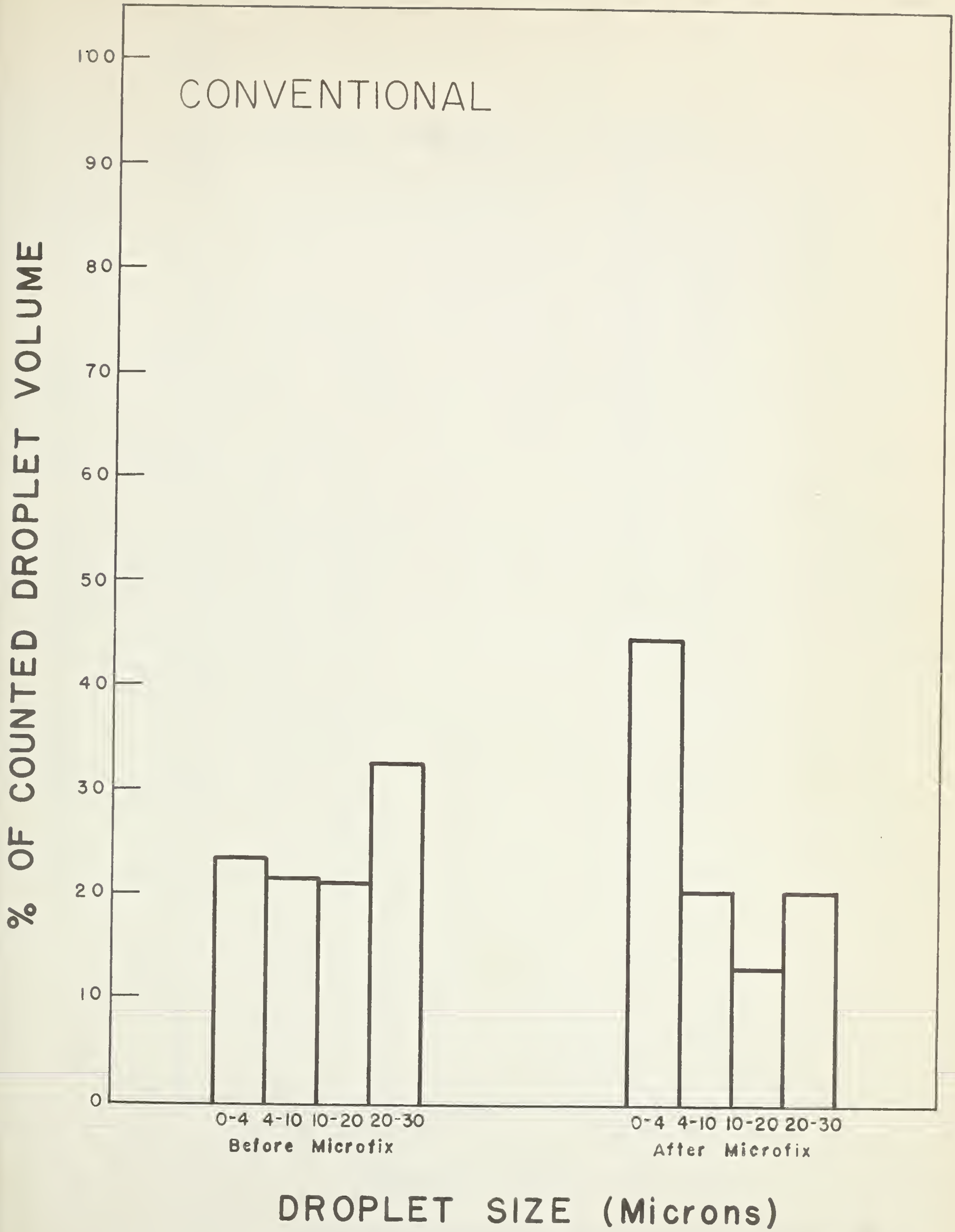

Fig. 6. Influence of homogenization on moisture dispersion in conventional butter stored at 40 F.

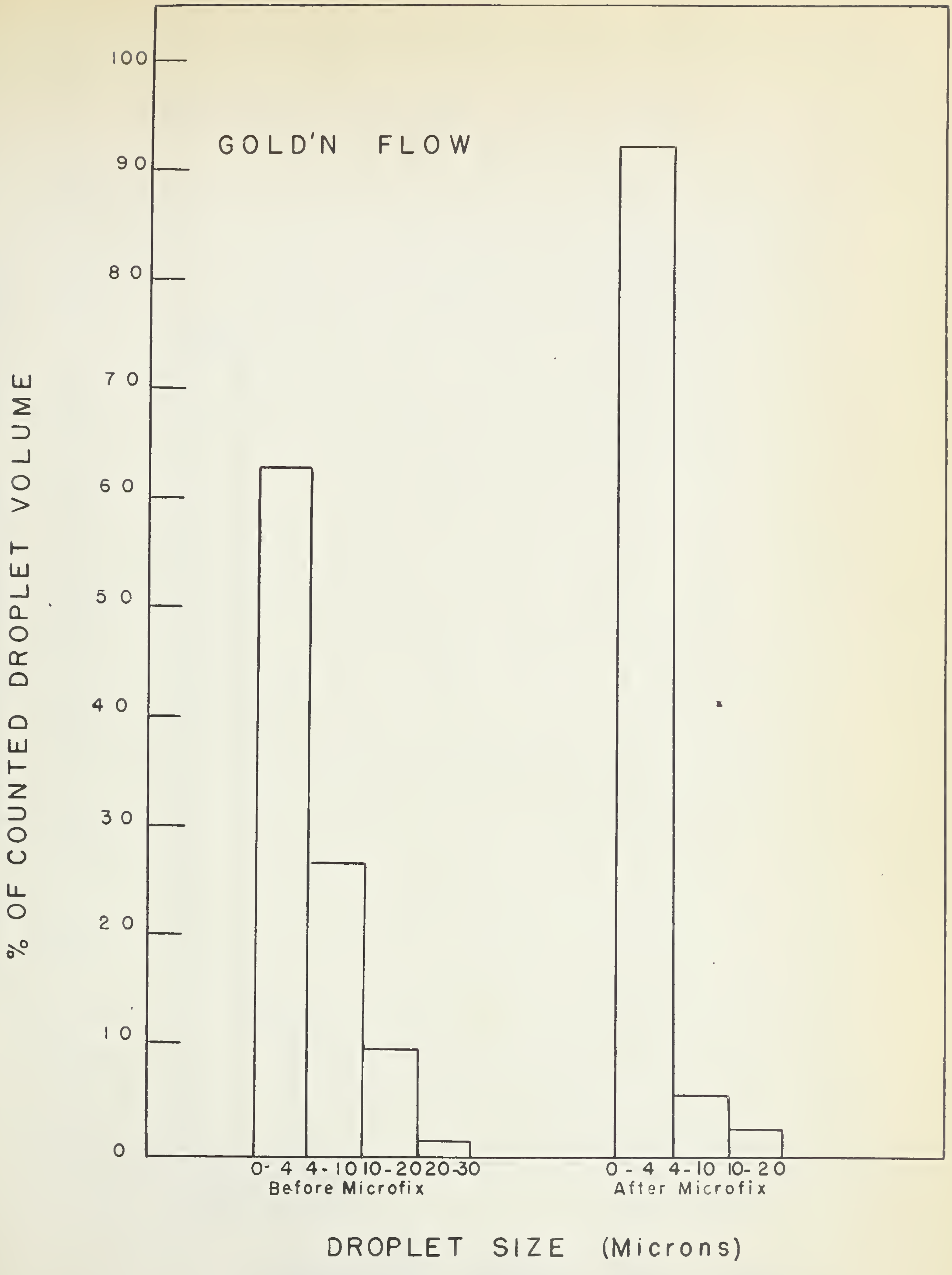

Fig. 7. Influence of homogenization on moisture dispersion in continuously made butter stored at 20 F.

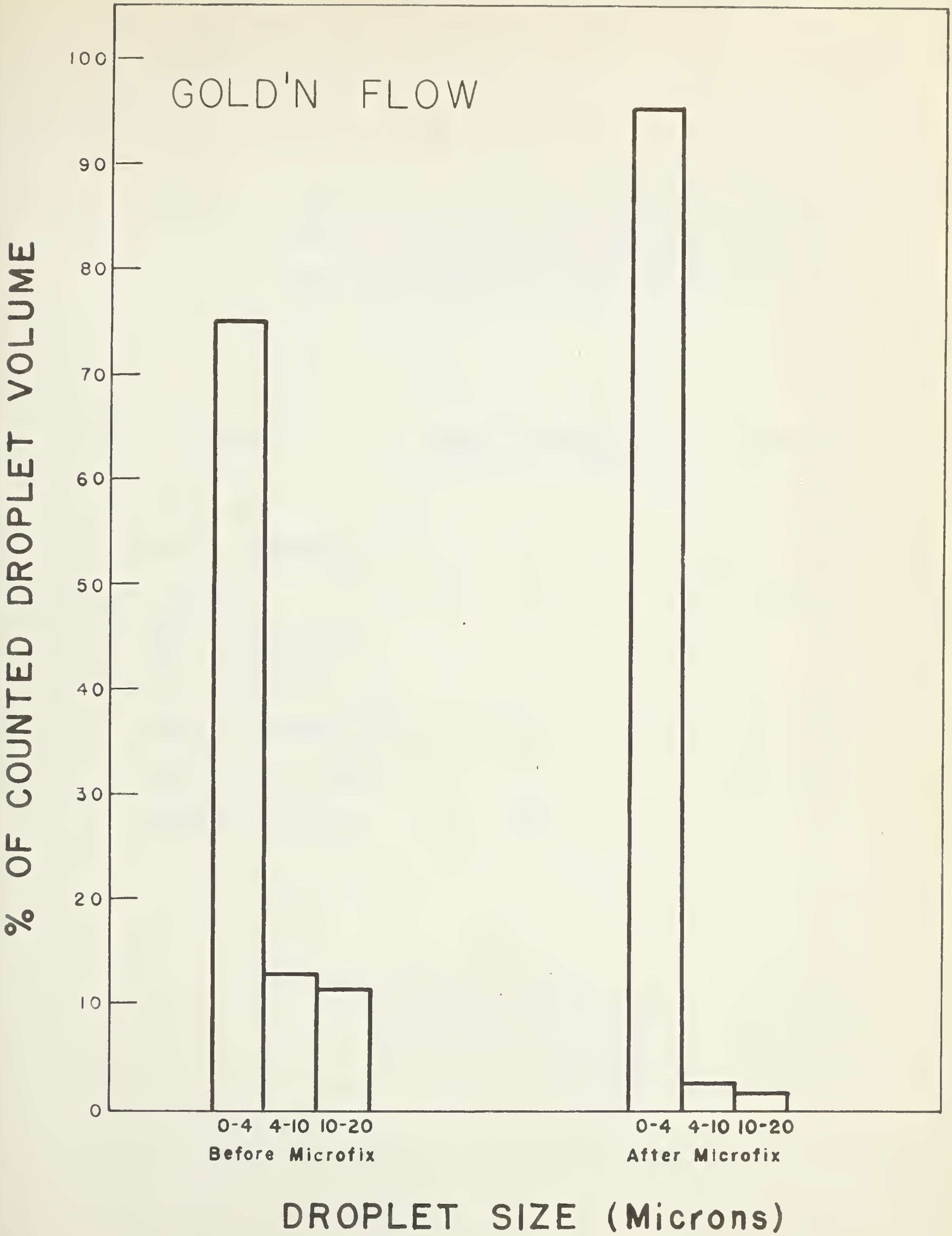

Fig. 8. Influence of homogenization on moisture dispersion in continuously made butter stored at 40 F.

Table 3. Analysis of Variance of water droplets of size 0 - 4 microns in Gold'n Flow and conventional types of butter homogenized after storage at 20°F and 40°F.

Sources	Degrees of Freedom	F ratio
Butter type	1	15.21**
Storage temperature	1	<1
Treatment	1	15.20**
Type x Temperature	1	<1
Type x Treatment	1	<1
Temp. x Treatment	1	<1
Type x Temp. x Treat.	1	<1
Error & replicates	32	

** Significant at $P = .01$.

Table 4. Analysis of Variance of water droplets of size 4 - 10 microns in Gold'n Flow and conventional types of butter homogenized after storage at 20°F and 40°F.

Sources	Degrees of Freedom	F ratio
Butter type	1	21.94**
Storage temperature	1	14.04**
Treatment	1	37.46**
Type x Temperature	1	1.64
Type x Treatment	1	3.87
Temp. x Treatment	1	6.72*
Type x Temp. x Treat.	1	1.12
Error & replicates	32	

** Significant at P = .01

* Significant at P = .05

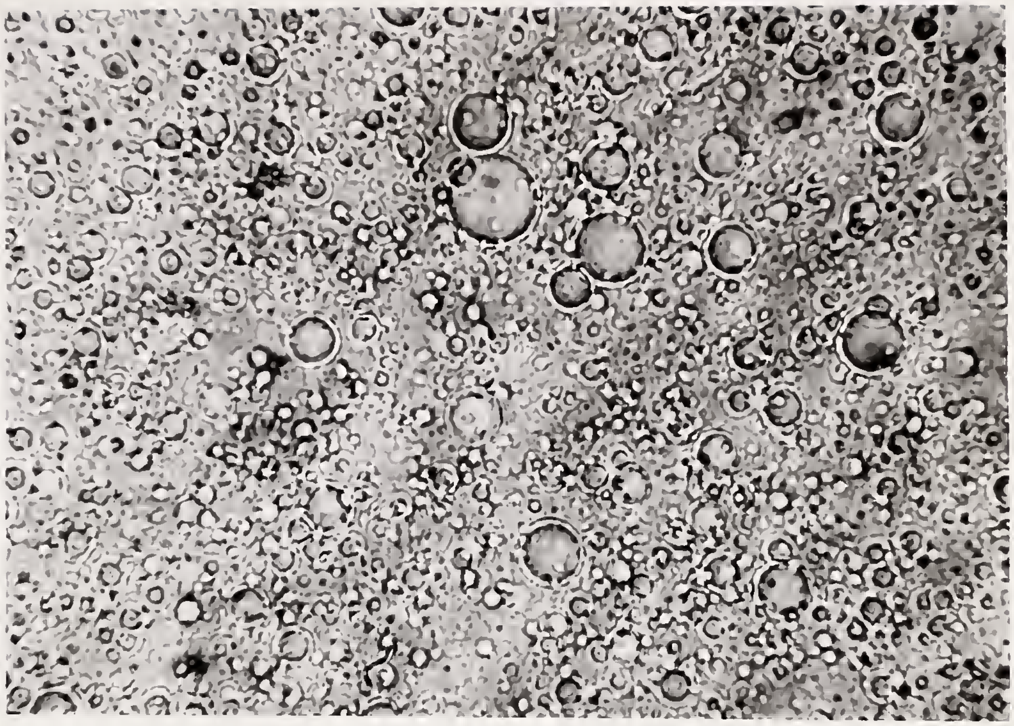

Fig. 9. Photomicrograph of the moisture dispersion in conventional butter before homogenization (magnification 950 x).

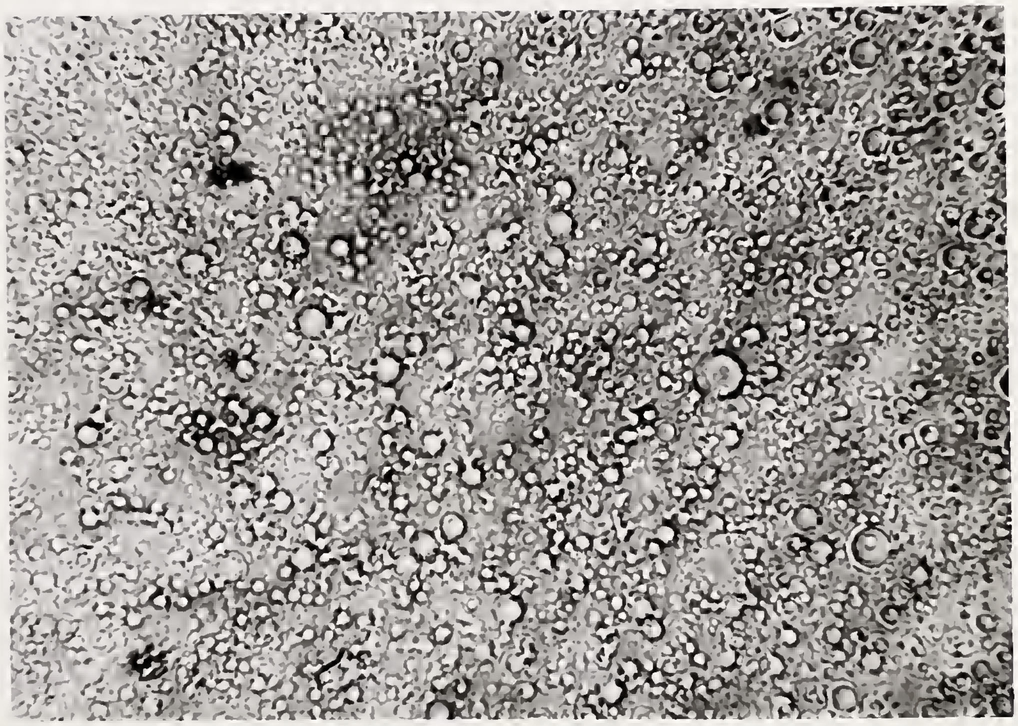

Fig. 10. Photomicrograph of the moisture dispersion in conventional butter after homogenization (magnification 950 x).

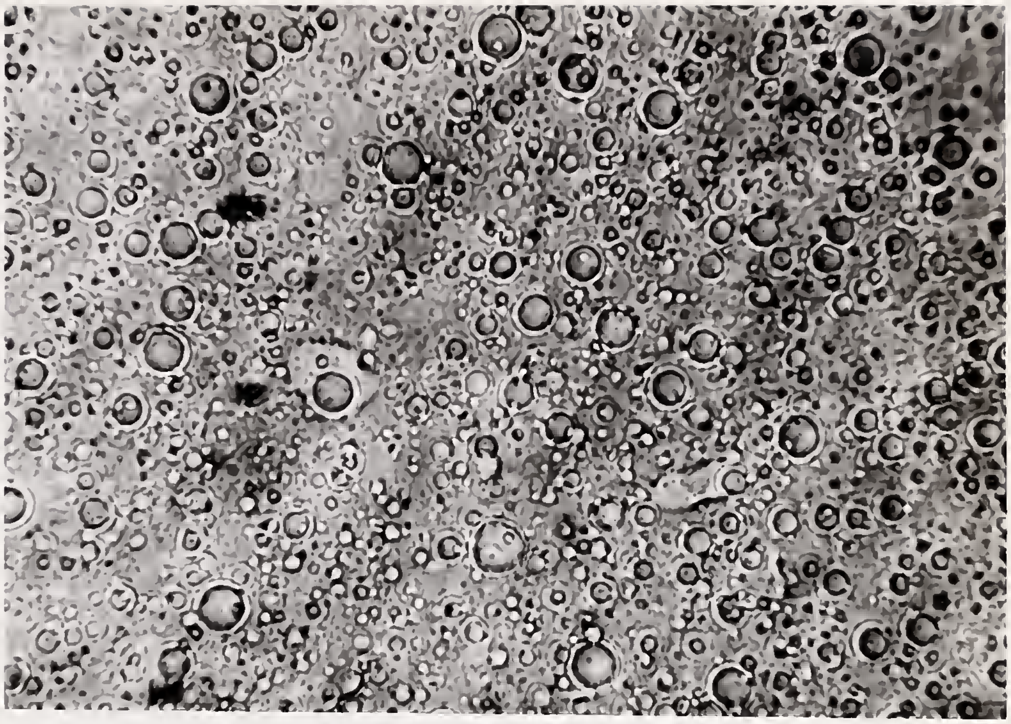

Fig. 11. Photomicrograph of the moisture dispersion in continuously made butter before homogenization (magnification 950 x).

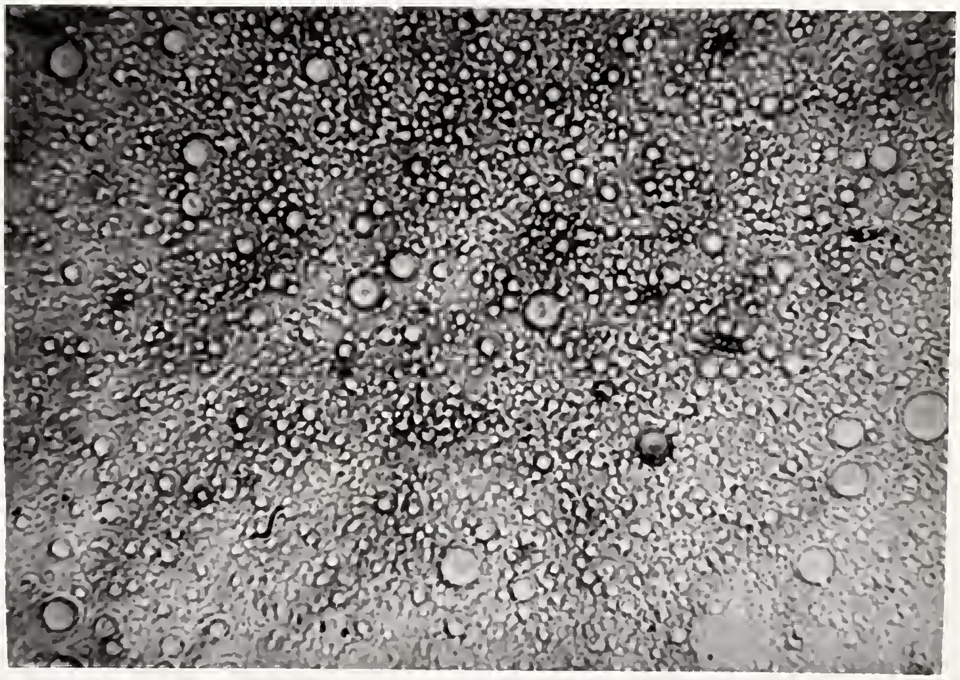

Fig. 12. Photomicrograph of the moisture dispersion in continuously made butter after homogenization (magnification 950 x).

Table 5. Influence of Fine and Coarse Rotors during homogenization of Gold'n Flow and conventional types of butter on moisture dispersion.

			No. of Droplets		
Butter Type	Samples	Rotor Type	0 - 4 µ	>4 - 10 µ	>10 µ
Gold'n Flow	1	Fine	6114	3	-
		Coarse	4760	3	1
	2	Fine	5879	1	-
		Coarse	5632	6	-
	3	Fine	9416	4	-
		Coarse	7582	12	-
Conventional	1	Fine	2854	15	4
		Coarse	1938	32	3
	2	Fine	2950	15	4
		Coarse	2604	29	4
	3	Fine	3206	25	5
		Coarse	1896	30	3

Comparison of Fine and Coarse Rotors.

Results of tests (Table 5) to determine the influence of fine and coarse rotors on the moisture dispersion when the butters were homogenized after storage at 20° F show that there was a significant difference ($P = .01$) in the effectiveness of dispersion. The fine rotor caused a greater increase in the number of droplets in the range 0 - 4 µ, while in the range over 4 - 10 µ, the coarse rotor caused more droplets to be formed. Droplets in the range over 10 µ did not appear to be influenced by the type of rotor.

Influence of Printers on Moisture Dispersion.

Butter is liable to become leaky when passed through printing machines. This was quite noticeable in observations made at various creameries. In all the printers under observation, with the exception of the Blanchet, a great deal of moisture was seen flowing from the machines and free moisture was visible on the surface of the printed butter.

Tests made with "Presto" indicator paper on a freshly cut slice of butter before and after printing, confirmed the first observations, that the texture of the butter was being changed by its passage through the printer. Plate 1 indicates that butter before printing was well worked and the moisture thoroughly incorporated with a consequent minimum of free moisture in some cases and none in other instances. After printing, all samples except that of the Blanchet, showed much free moisture on the butter surface.

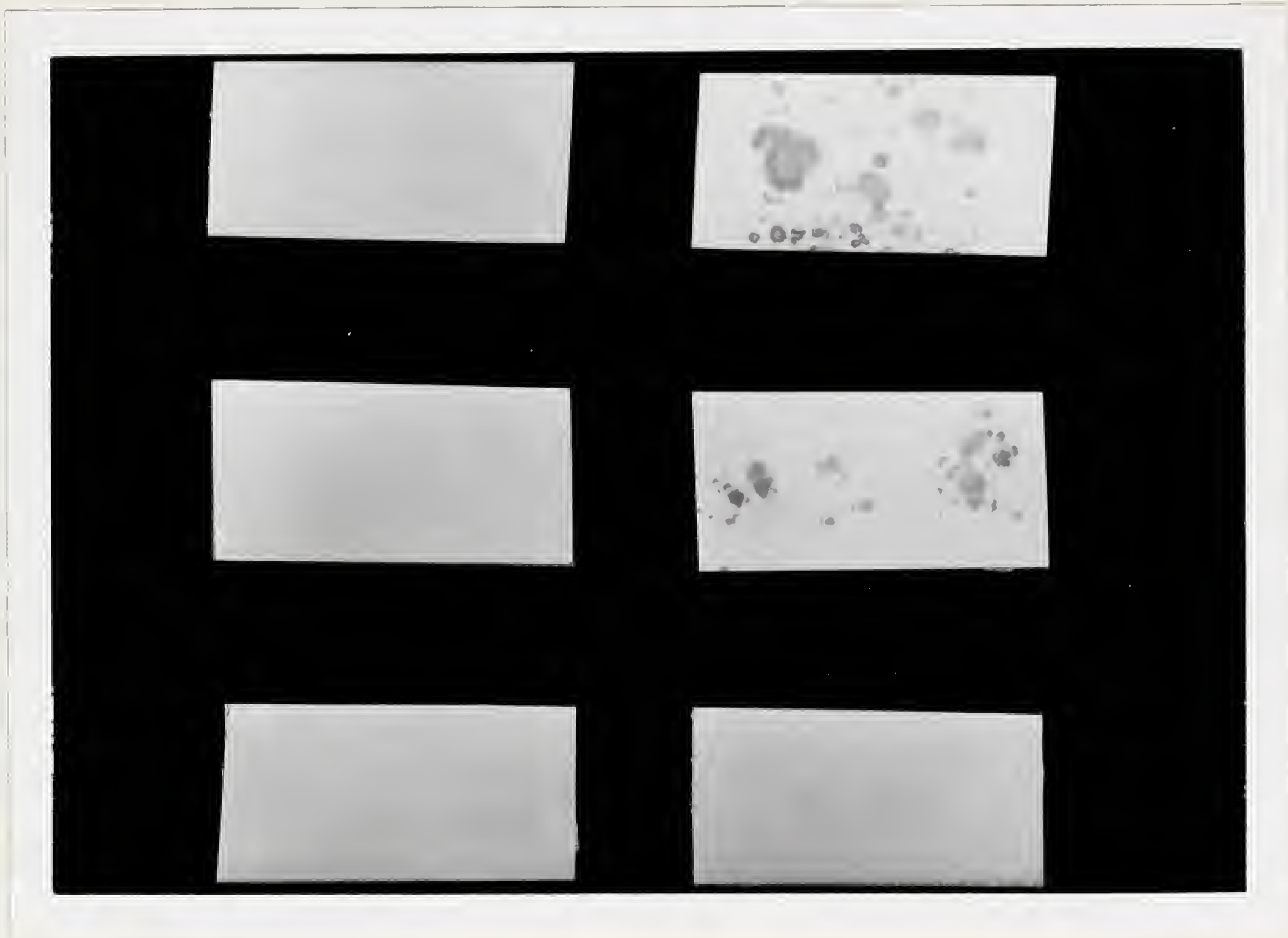

Plate 1. Effect of printers on butter samples as shown by "Presto" indicator paper.

Top left - before printing. Top right - after printing in Kustner.
Centre left - before printing. Centre right - after printing in B.M.R.
Bottom left - before printing. Bottom right - after printing in Blanchet.

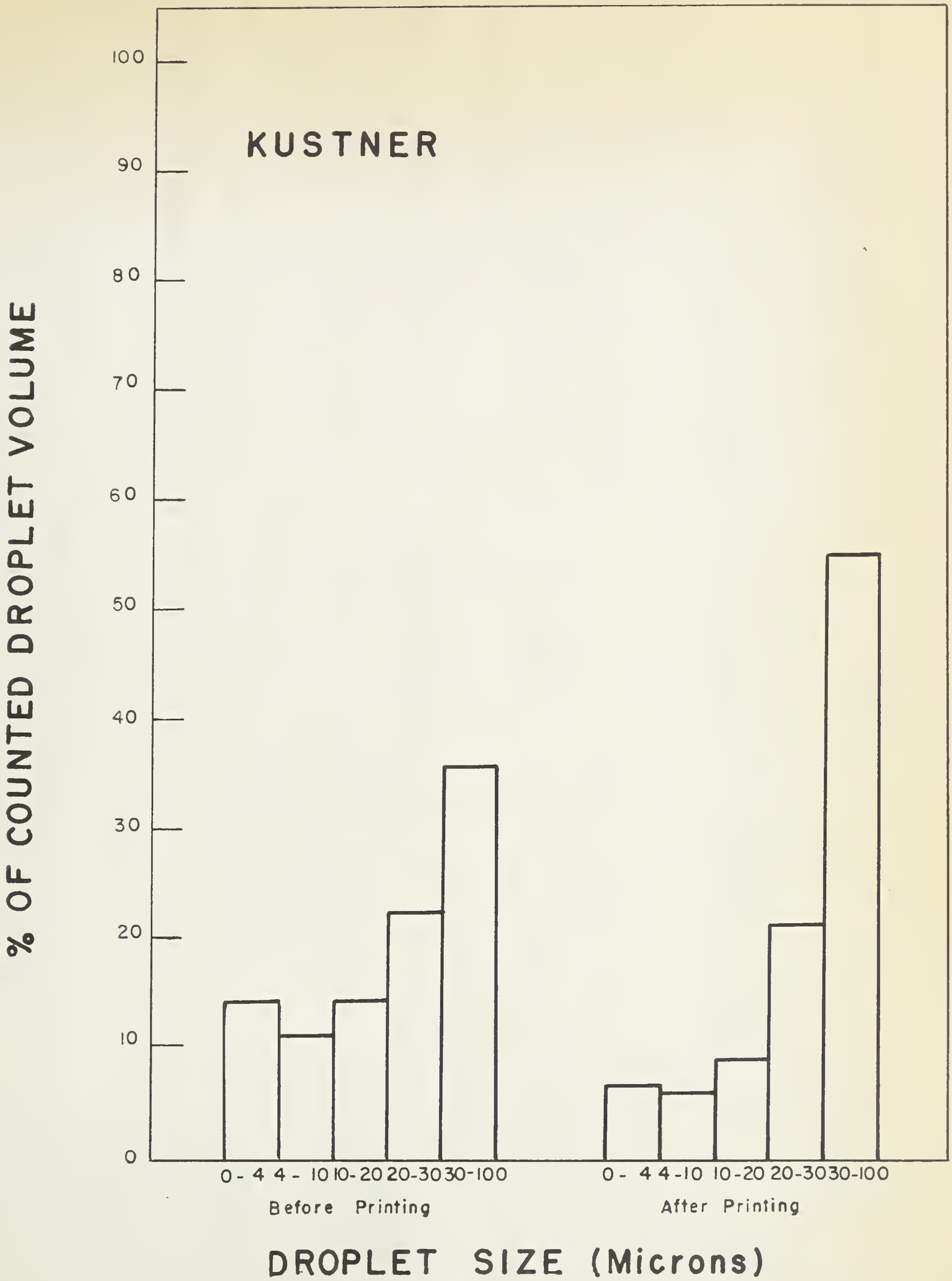

Fig. 13. Influence of printing in a Kustner printer on moisture dispersion in conventional butter.

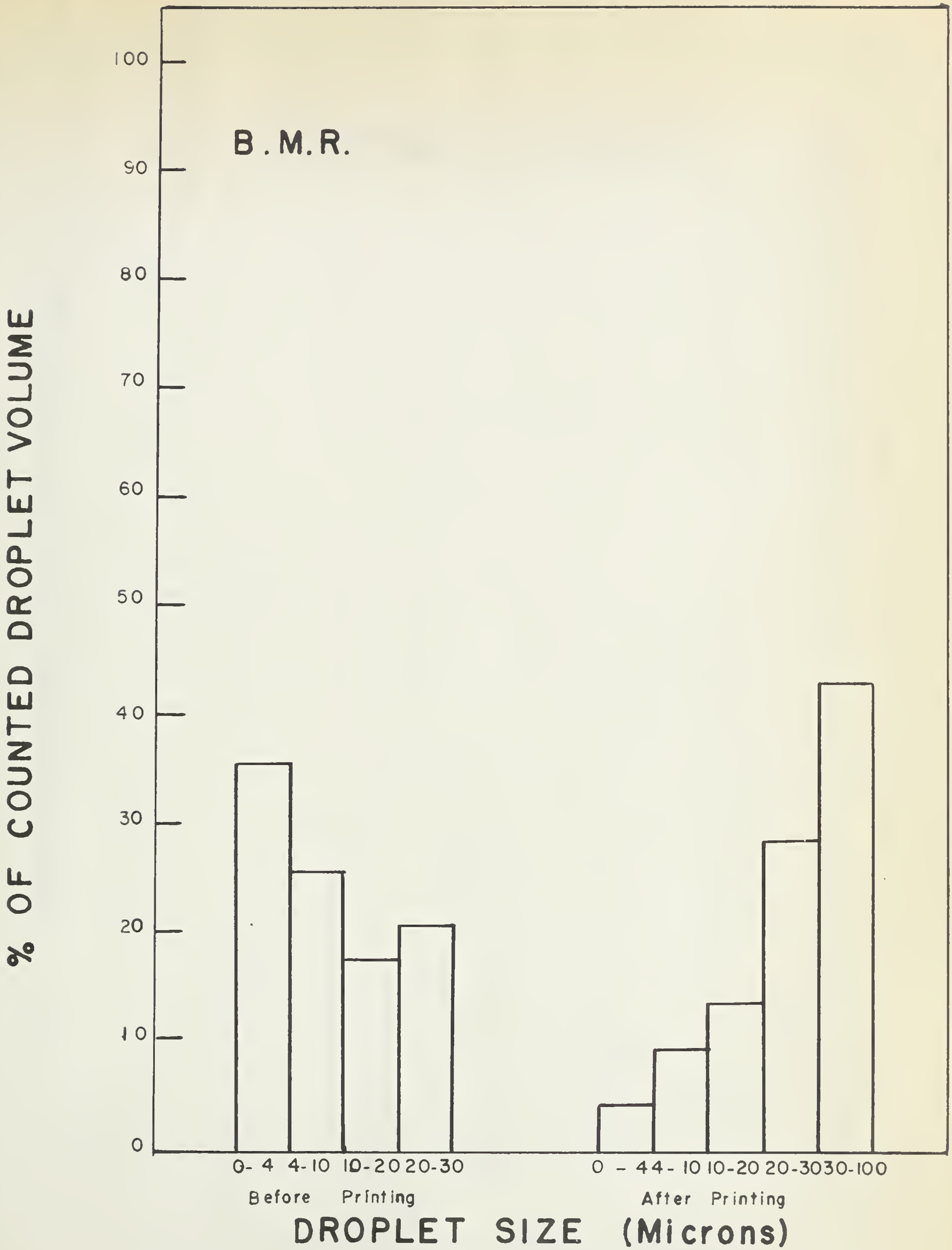

Fig. 14. Influence of printing in a B.M.R. printer on moisture dispersion in conventional butter.

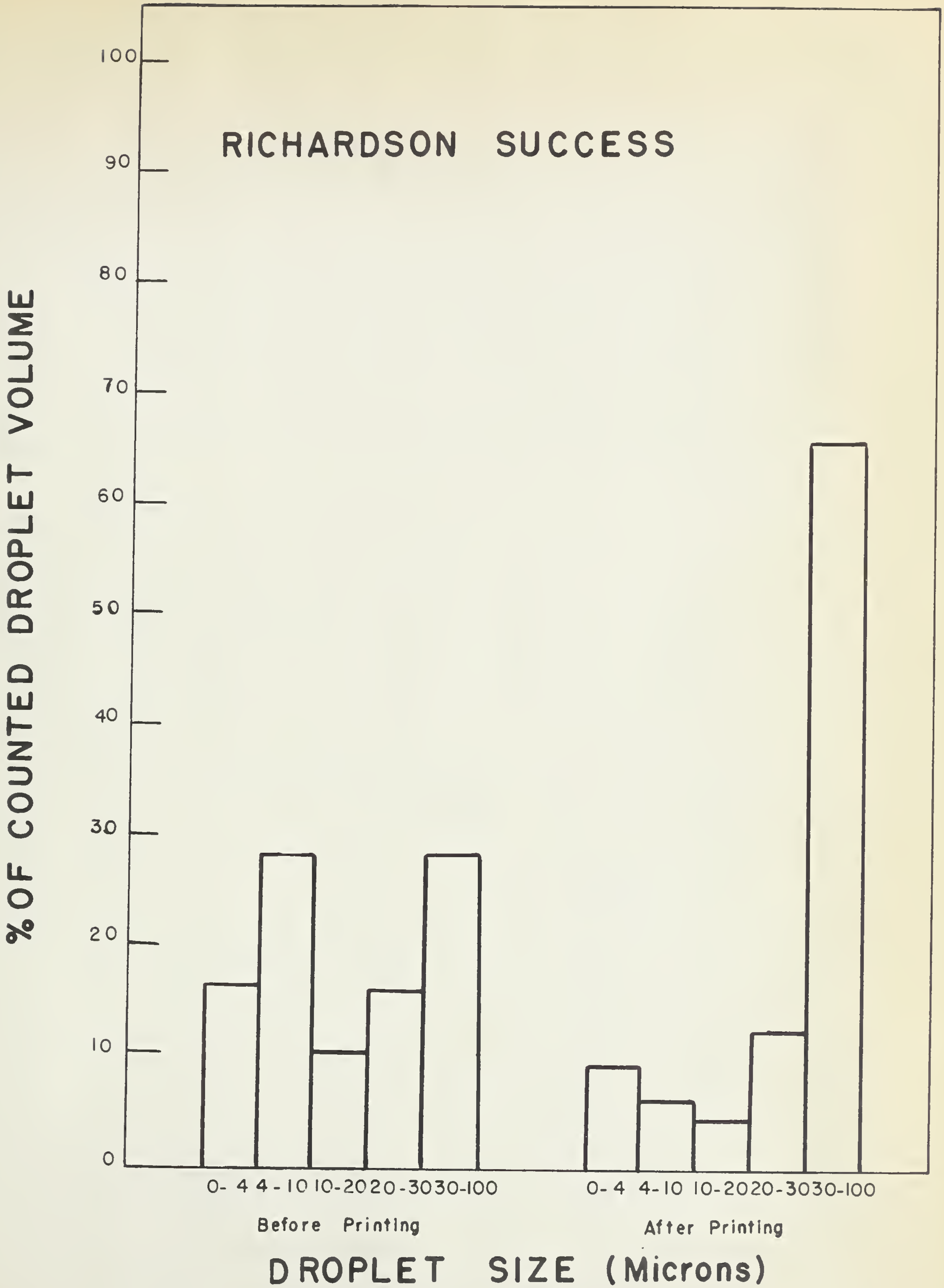

Fig. 15. Influence of printing in a Richardson Success printer on moisture dispersion in conventional butter.

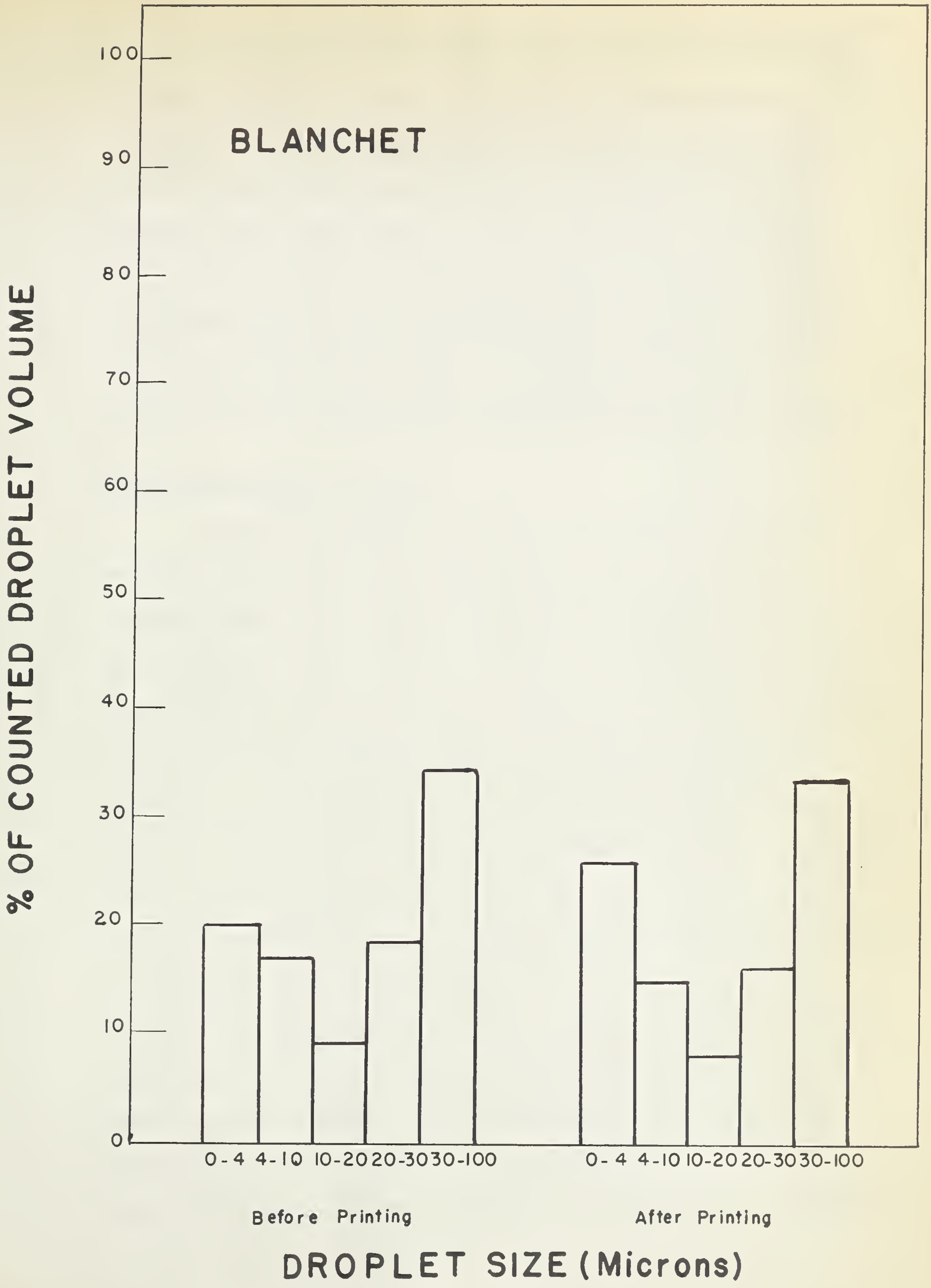

Fig. 16. Influence of printing in a Blanchet printer on moisture dispersion in conventional butter.

Direct microscopic counts were made to determine the size of droplets before and after printing and to obtain some idea of the amount of coalescence of the moisture droplets taking place. Butters printed in the Kustner, B.M.R. and Richardson "Success" printers show a trend towards reversal of the amount of moisture in the various droplet size ranges (Figures 13, 14 and 15). The moisture dispersion of butter printed in the B lanchet (Figure 16) appears to be more or less the same as that before printing, indicating that the texture was not disturbed to any marked degree.

Commercial Samples of Butter.

Hesion measurements were made on commercial samples of conventional and continuously made butter obtained from two Edmonton creameries. Table 6 shows that the conventional butters had higher hesion values than the continuously made butters. These results indicate that the method of manufacture was partly responsible for the difference in hesion values. The characteristic crystal structure of a continuously made and conventional butter sample studied in these trials is shown in Figures 17 and 18. It is evident from these polarized light photomicrographs that the continuously made butter contains larger fat crystals than the conventional butter. In conventional butter, the butterfat crystals are very small, having been formed inside the globule. The crystallization is initiated at the membrane because of the presence of crystal centres provided by the membrane material. During churning, when the globules are disrupted, a very large quantity of extremely small crystals is released. However, a large percentage of the crystalline butterfat

Table 6. Hesion measurements (g)* on commercial samples of conventional and continuously made butter.

Samples	Conventional	Continuously made (commercial)
1	81.5	38.4
2	87.5	48.3
3	85.9	59.8
4	74.2	47.1
5	91.3	58.6
6	102.4	68.1
7	119.5	73.0
8	114.1	56.6
9	134.6	63.0
10	126.4	87.4

* Each value is the average of 45 measurements.

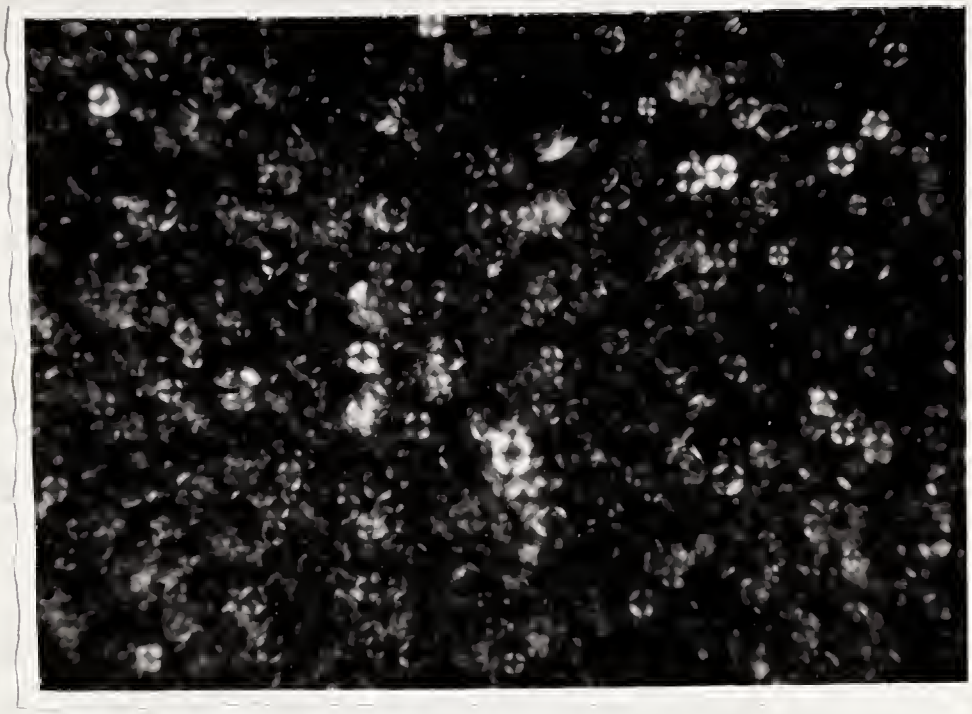

Fig. 17. Polarized light photomicrograph of the crystal structure in commercial conventional butter.

Fig. 18. Polarized light photomicrograph of the crystal structure in commercial continuously made butter.

is enclosed in the fat globules not destroyed in the churning and working of the butter. (de Man and Wood, 1958c).

Influence of homogenization on hesion values of commercial butters.

When commercial samples of conventional and continuously made butters were subjected to homogenization, the hesion values increased substantially; an indication that the process produced a considerable change in the structure of the butter. These data are summarized in Table 7.

Influence of butter types on hesion value.

In these experiments, butters made from the same butterfat source were used in order to eliminate the variability that might be attributed to the chemical composition of butterfat. The results of hesion and hardness for 8 trials are reported in Tables 8 and 9. Table 8 shows that the conventional butters had the highest hesion values, followed by precrystallized and non-precrystallized continuously made butters. According to the data in Table 9, the order of the butters for hardness values was reversed, with non-precrystallized continuously made butter having the highest value, followed by precrystallized continuous and conventional butters. A comparison of Tables 8 and 9 indicates that generally the hesion values were highest when the hardness values of the butters were lowest.

Influence of reworking in a laboratory blender on hesion value.

The results in Tables 7, 8 and 9 indicate that the structure

Table 7. Effect of homogenization on hesion values (g)* in commercial conventional and continuously made butters.

Butter Type	Samples	Before Homogenization	After Homogenization
Conventional	1	21.53	50.36
	2	81.49	118.51
	3	87.53	122.95
Continuously made (commercial)	4	38.37	47.33
	5	47.11	150.47
	6	48.27	113.96
	7	59.82	74.60

* Each value is the average of 45 measurements.

Table 8. Hesion values (g)* of conventional and continuously made precrystallized and non-precrystallized butters from the same butterfat source.

Trials	Conventional	Continuously made	
		non-precrystallized	precrystallized
1	102.4	58.6	84.9
2	114.1	70.8	115.8
3	114.7	82.6	102.8
4	119.5	72.9	105.8
5	112.0	90.3	87.4
6	134.6	98.9	96.1
7	85.9	58.6	107.2
8	91.3	30.3	64.4
Average	109.3	70.4	95.6

* Each value is the average of 30 readings.

Table 9. Hardness values ($Kg/4cm^2$) of conventional and continuously made butters from the same butterfat source.

Trials	Conventional	Continuously made	
		non-precrystallized	precrystallized
1	2.00	2.45	2.18
2	1.86	2.32	1.95
3	2.05	2.40	2.13
4	2.02	3.53	2.13
5	2.19	2.90	2.77
6	1.92	2.15	2.09
7	3.19	5.32	4.30
8	2.82	4.17	3.86
Average	2.26	3.16	2.68

of the butter, as it influenced hardness, had a significant effect on the hesion value. Experiments were therefore conducted on the effect which reworking would have on the hesion values, since it was to be expected that reworking would have an influence on the structure of the butter. The results obtained for hardness, oiling-off and hesion values for butters manufactured from the same butterfat source are presented in Tables 10, 11 and 12. In Table 10, for conventional butter, there did not seem to be any significant change in the hardness value, even after 30 minutes of reworking, whereas in the continuously made butters, there was an effective reduction in hardness after 10 minutes of reworking. For conventional butter, Table 11, the oiling-off percentages did not change much, whereas in the continuous butters, there was a large decrease after 10 minutes of reworking and after 40 minutes, there was a slight increase, these results being paralleled by increased hardness. Table 12 shows that in both conventional and precrystallized continuously made butter, the maximum hesion values were obtained after 10 minutes of reworking, whereas in the non-precrystallized continuous butter, maximum hesion was attained after 20 minutes of reworking. Figures 19, 20 and 21 show that there was a relationship between hardness and hesion values, i.e., with an increase in hardness, there was a decrease in hesion and <u>vice versa</u>. This was not very apparent in conventional butter (Figure 19) and will be discussed elsewhere.

<u>Influence of gas content on hesion value.</u>

This study was restricted to laboratory continuously made

Table 10. Influence of reworking in the laboratory blender on hardness ($Kg/4cm^2$) of conventional and continuously made butter from the same butterfat source.

Time of Reworking min	Conventional	Continuously made	
		non-precrystallized	precrystallized
0	3.19	5.32	4.30
10	3.19	3.86	2.15
20	3.09	3.64	2.54
30	3.28	3.63	2.27
40	----	4.17	2.26

Table 11. Effect of reworking in the laboratory blender on the oiling-off percentages* of conventional and continuously made butters from the same butterfat source.

Reworking Time (min)	Conventional	Continuously made	
		non-precrystallized	precrystallized
	%	%	%
0	8.38	15.06	11.17
10	8.12	9.13	9.38
20	7.15	8.56	9.24
30	8.30	8.60	9.55
40	---	10.96	9.72

* Each value is the average of duplicate samples.

Table 12. Influence of reworking in the laboratory blender on hesion values (g)* of conventional and continuously made butters from the same butterfat source.

Reworking Time (min)	Conventional	Continuously made	
		non-precrystallized	precrystallized
0	85.9	58.6	107.2
10	151.8	154.7	168.1
20	141.6	170.5	147.5
30	102.0	157.9	153.9
40	----	108.1	151.8

* Each value is the average of 30 measurements.

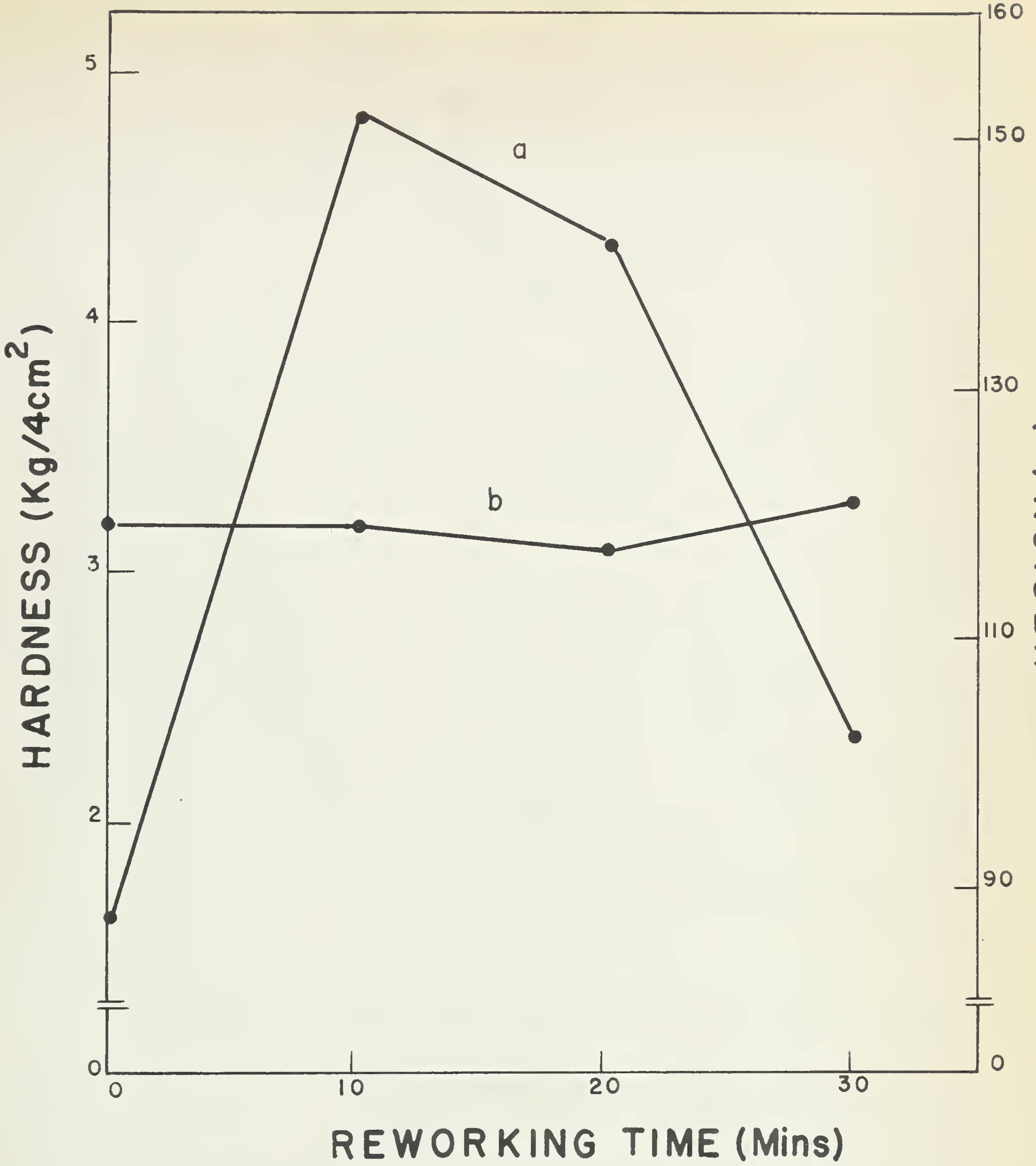

Fig. 19. Influence of reworking on hesion (curve a) and hardness (curve b) of conventional butter.

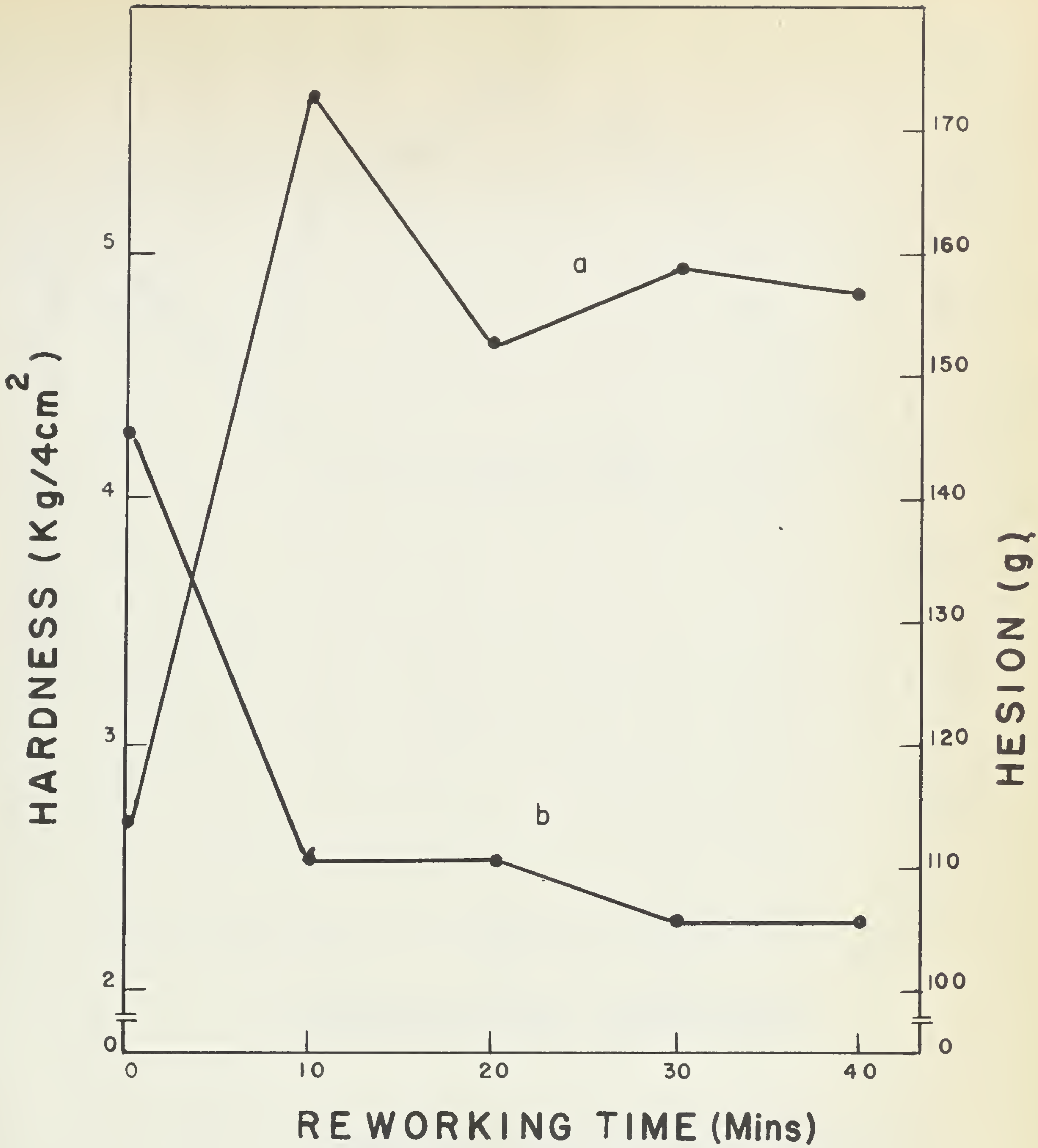

Fig. 20. Influence of reworking on hesion (curve a) and hardness (curve b) of continuously made pre-crystallized butter.

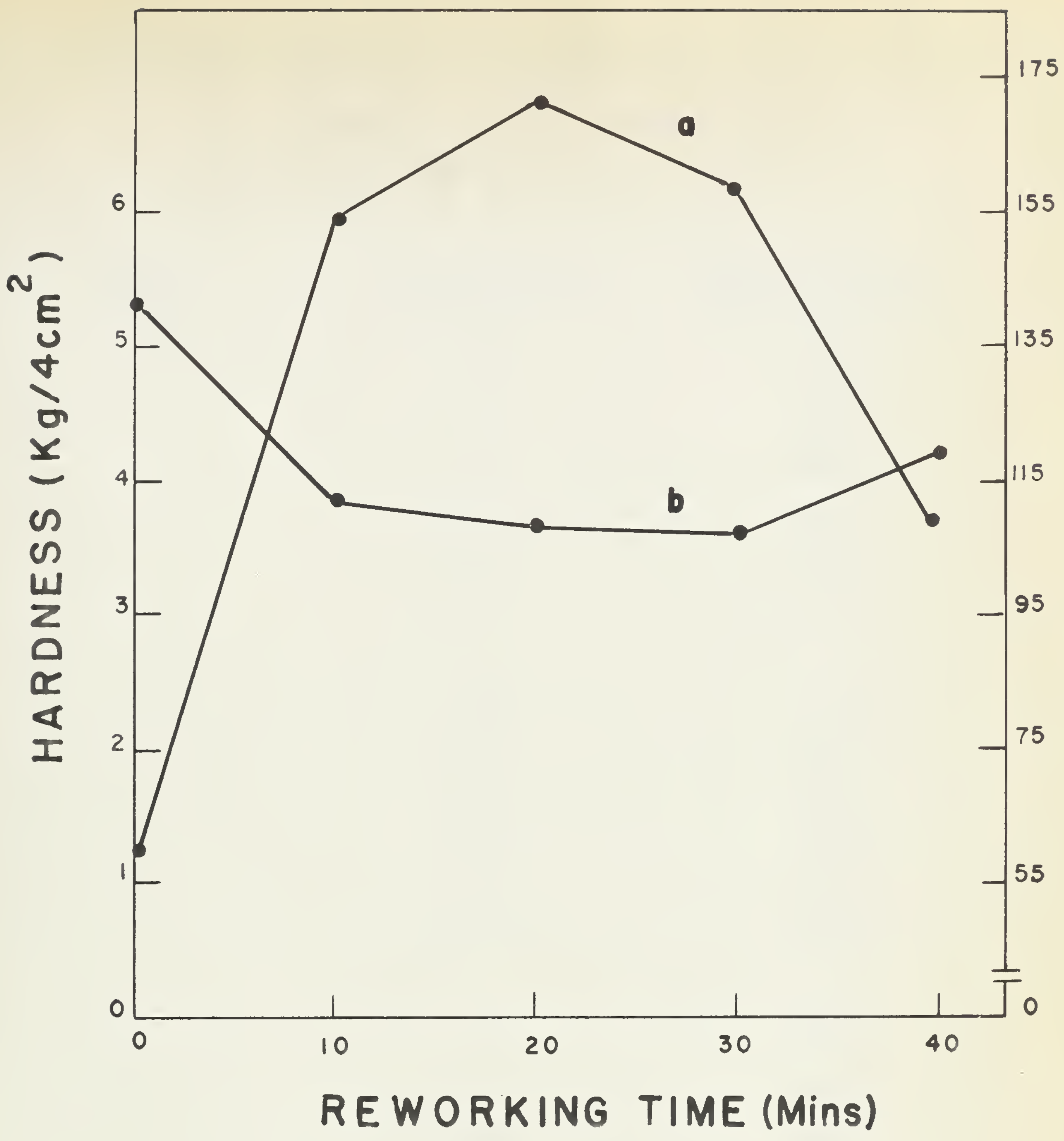

Fig. 21. Influence of reworking on hesion (curve a) and hardness (curve b) of continuously made non-precrystallized butter.

Table 13. Influence of gas content on the hesion values of continuously made precrystallized butter.

Trials	Gas Content (%)	Hesion Value (g)*
1	< 0.10	96.1
	1.06	93.7
	3.36	100.3
	4.45	100.5
	12.62	55.8
2	< 0.10	87.4
	0.55	103.6
	3.20	62.8
	9.03	63.0
	16.07	56.6
3	< 0.10	102.8
	0.36	107.2
	6.08	84.8
	17.94	73.0
	23.39	68.1

* Each value is the average of 30 measurements.

Table 14. Influence of gas content on the hardness values of continuously made precrystallized butter.

Trials	Gas Content (%)	Hardness Value ($Kg/4cm^2$)
1	$<$ 0.10	2.82
	1.06	2.26
	3.36	2.18
	4.45	2.15
	12.62	1.51
2	$<$ 0.10	2.13
	0.55	2.11
	3.20	1.93
	9.03	1.46
	16.07	1.40
3	$<$ 0.10	2.77
	0.36	2.07
	6.08	1.62
	17.94	1.37
	23.39	1.31

Table 15. Influence of gas content on the hesion and hardness values of conventional butter.

Trials	Gas Content (%)	Hesion Values (g)*	Hardness Value ($Kg/4cm^2$)
1	.14	148.4	2.12
	1.49	129.6	2.00
2	.18	135.5	2.86
	2.20	113.3	2.04
3	.08	119.6	2.65
	1.65	89.3	2.22

* Each value is the average of 45 measurements.

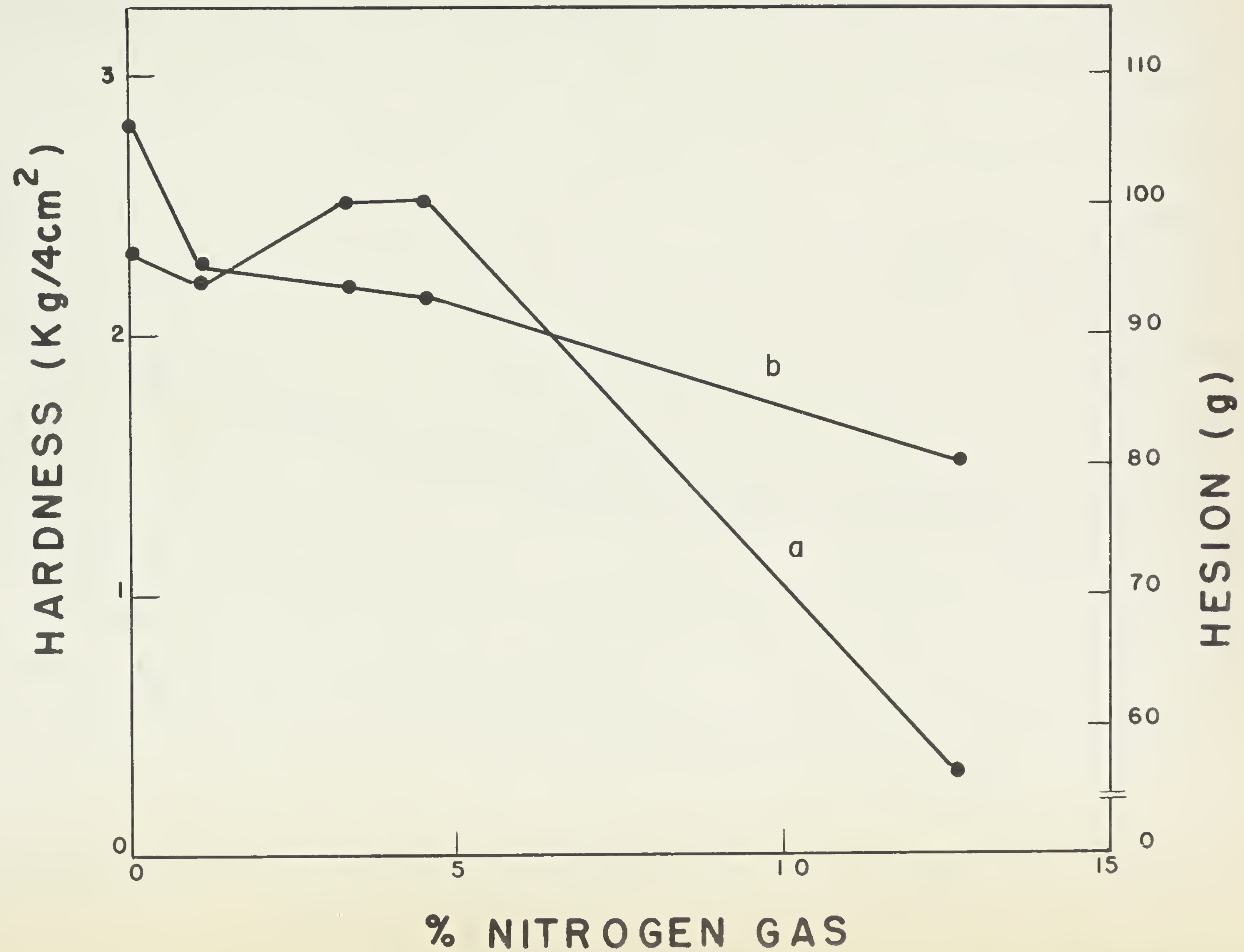

Fig. 22. Influence of gas content on hesion (curve a) and hardness (curve b) of continuously made precrystallized butter (Trial 1).

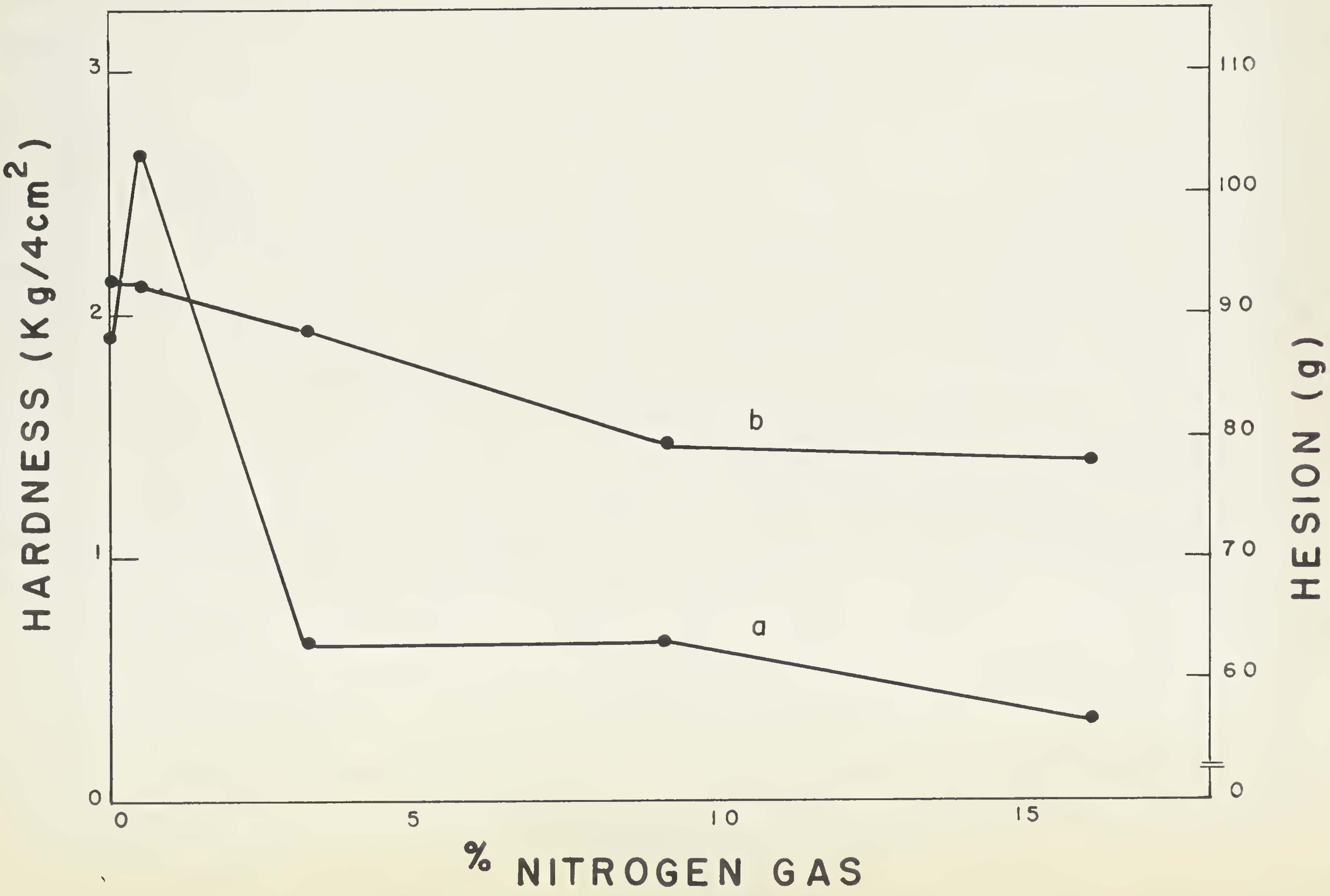

Fig. 23. Influence of gas content on hesion (curve a) and hardness (curve b) of continuously made precrystallized butter (Trial 2).

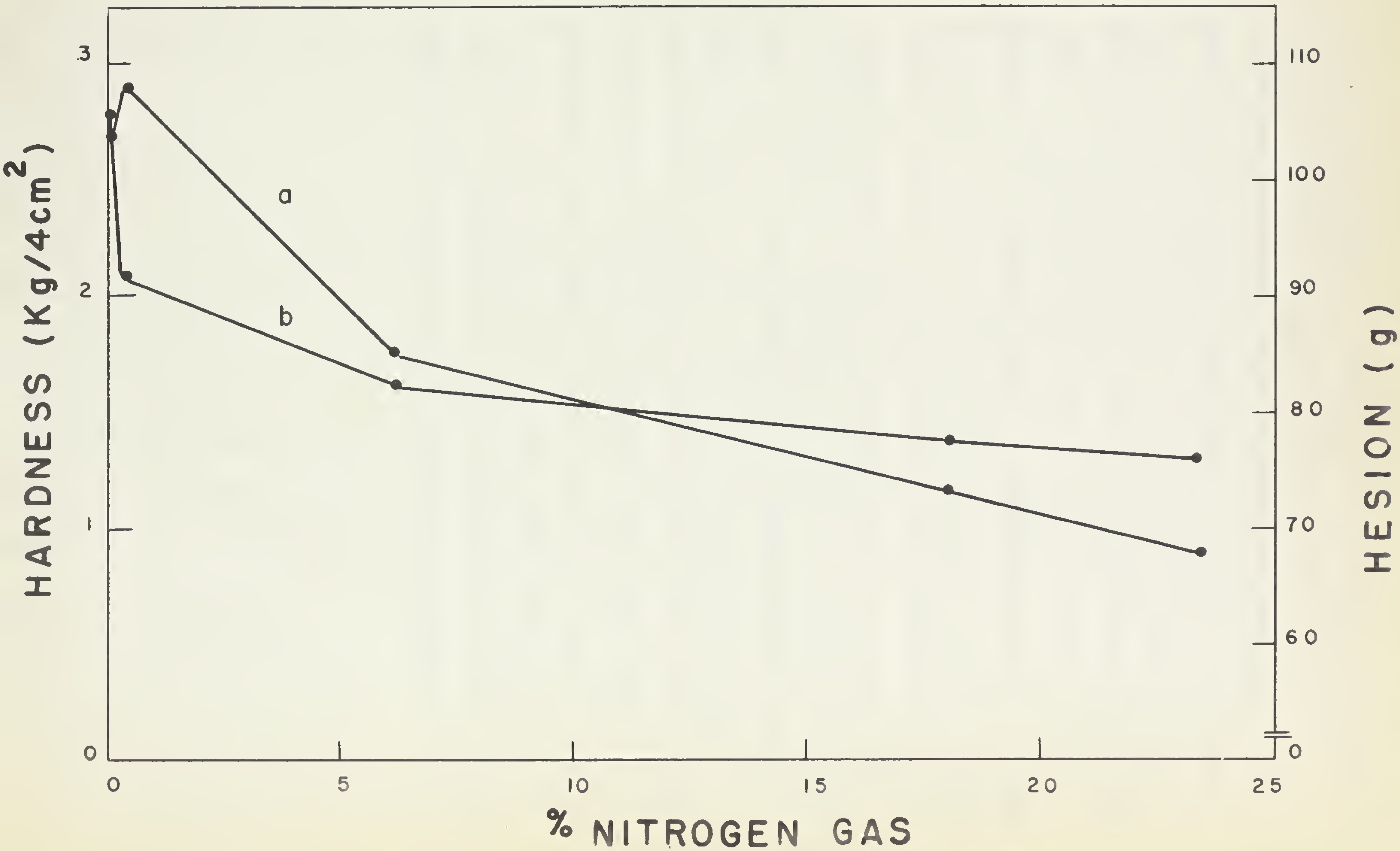

Fig. 24. Influence of gas content on hesion (curve a) and hardness (curve b) of continuously made precrystallized butter (Trial 3).

precrystallized butter to which air could be added in the manner described elsewhere, and to conventional butter worked in a blender with and without vacuum and described previously. The results obtained for hesion and hardness values in 3 trials are shown in Tables 13, 14 and 15. There was a reduction in hardness with increasing gas content in both the continuous and conventional butters. The hesion values in Table 13 show that with a small increase in gas content, there was an increase in hesion. However, when the gas content exceeded the normal range (2 - 3%) and reached values as high as 12% or more, hesion values decreased. With the decrease in hesion values as a consequence of the increased gas content, there was an increase in the amount of butter that remained attached to the contact surface of the adherend when it became detached from the butter. In conventional butter, this same observation was apparent when comparing the contact surface of the adherend after detachment from butters worked under vacuum and butters worked without vacuum. Figures 22, 23 and 24 show the relationship which existed between hesion and hardness. In this case, the hardness values were determined by the gas content and the hesion values were higher when the gas content was low.

DISCUSSION

Influence of Homogenization on Moisture Dispersion.

Both conventional and continuously made butter stored at 20° F and 40° F before homogenization showed significant increases in the moisture dispersion after homogenization in a Microfix unit. The moisture droplets were more finely divided, resulting in an increase in the volume of droplets in the droplet size range of 0 - 10 microns and a decrease in the range over 10 microns. The working principle of the unit was responsible for this extensive subdivision of the moisture droplets. The rotor cut the butter into paper-thin slices, because the clearance between rotor and rotor housing was 1 mm, thus limiting the thickness of the slice that was removed. (Pedersen, 1960). This removal of a paper-thin slice over the entire surface of the column of butter being forced into the rotor head produced a subdivision of the droplets. The droplets were further subdivided when the rotor deposited this thin slice of butter on the surface of the outgoing butter. Results in Table 5 indicate that the type of rotor influenced the subdivision of these droplets. This was quite possible, because with the finer mesh rotor, the working intensity was greater than with the coarse rotor. The fine rotor has 30 blades, while the coarse rotor has only 16 blades. The size of the droplets which occur in greatest numbers after working depends on the number and size of the drops before working and also on the intensity of working. Therefore,

it was not surprising that there was a much larger volume of droplets in the 0 - 10 micron range in continuously made butter, when compared to conventional butter after homogenization, because the volume of droplets in this range was greater in Gold'n Flow butter before homogenization.

It appears that the storage temperature had an influence on the droplet size. Analysis of Variance test shows that there was a significant difference in the volume of droplets in the 0 - 4 micron droplet range of butter stored at 40°F, as a consequence of the homogenization treatment. However, in the 4 - 10 micron range, the difference was a result of both the treatment and the storage temperature. Apparently, as a consequence of storage at 20°F, there was a larger number of droplets in the 4 - 10 micron range. Prentice (1954) stated that if the temperature of the butter is lowered so that the water freezes, the water expands as it turns to ice and stresses are set up in the surrounding fat which is almost all solid at these temperatures. These stresses may be sufficient to rupture any fat layers which are mechanically weak, so that when the butter is thawed out again, the water droplets which were originally separated by these layers may coalesce. Sukegawa and Taneya (1957) stated that coälescence of water droplets occurred in butter stored at -5°C (23°F), but decreased in butter stored at 8°C (46.4°F). They also indicated that when butter was stored at 8°C for 5 to 7 days and the temperature changed to -5°C or 10°C, coalescence of water droplets did not take place.

Since the crystalline fat keeps the water droplets dispersed in the butter, this appears to be logical, because in this period of time at a temperature of 8° C, the crystalline fat would be stabilized as the butter would have set.

The moisture dispersion of both Gold'n Flow and conventional types of butter was improved considerably when these butters were subjected to homogenization.

Influence of Printers on Moisture Dispersion.

All the printers observed, with the exception of the Blanchet, caused a condition of free moisture with a consequent loss of moisture during printing. Large dimension of drops, high velocity gradient and high viscosity favour bursting of droplets (Mulder & Den Braver, 1956a). Coalescence and rupture of water droplets occur at the same time when butter is worked. Circumstances determine which process predominates. The size of droplets which occur in greatest numbers after working depends on the number and size of the drops before working and the intensity of working. When the working is vigorous, the droplet sizes are small and the butter is dry. However, in the printers observed which employ the Archimedean screw principle, the augers which work the butter move too slowly to cause a high gradient of velocity, which is one of the factors necessary for a finer moisture dispersion. Therefore, with the gentle working which the butter receives in the printers, a high proportion of large drops and consequently leaky butters are obtained.

In the Blanchet, the mechanism involved is that of two

polygonal rolls which assist in pushing the butter into the moulding compartment. The butter is comparatively soft because after manufacture, it is held in storage overnight before it is printed. The droplets tend to remain apart and the gentle action of the rolls does not greatly disturb the structure of the butter. This accounts for the lack of free moisture observed in butter printed in this machine.

Printers used for moulding butter that has been allowed to set are generally unsatisfactory, since they promote leakiness and loss of weight in the butter. If it were possible to include in the printers a rotor type feature similar to the homogenizer, where the butter could be worked more vigorously, the problem of free moisture and leaky butter might be eliminated.

Influence of Manufacturing Methods on Hesion Values.

The results in Table 7 indicate that the manner in which cream was made into butter influenced the hesion values. According to Mulder (1949), the physical structure of butter is influenced by the method of manufacture, the structure of the materials used in the manufacture and the treatment of the butter after its manufacture.

"The crystal form size and arrangement in continuously made butter are characteristic and different from conventional butter." (de Man, 1959). de Man found that in continuously made butter, there was an absence of globular fat and the presence of relatively large crystals. These large crystals were present in spite of the

rapid cooling and violent agitation in the chiller, which ordinarily produced very small crystals in butterfat. Apparently, crystallization is not complete when the butter leaves the chiller, since butter, after leaving the chiller and held under adiabatic conditions, showed a temperature increase of up to 50°F. When the fat crystals from the chiller move into the texturator, conditions are ideal for further growth. On the other hand, in conventional butter, the crystallization process is practically complete before churning. Here the fat crystals are also limited by the size of the fat globules. According to McKnight and Wood (1962), there was an increase in crystal size when butter made in the laboratory continuous butter making machine was allowed to pass through the precrystallizing unit.

However, besides the size of the fat crystals, the ratio of solid to liquid butterfat is an important factor in determining butter hardness. Winter butter is normally harder than summer butter and the variations in the chemical composition are mainly responsible. Among the variables is included the glyceride composition of the butterfat. Mixed crystals contain glycerides of different melting points and a rapidly cooled fat will have a lower melting point than the same fat which is cooled slowly. Mixed crystal formation leads to an increased content of the crystalline phase when compared with a fat in which no mixed crystals are present. Wood and de Man (1956) stated that the higher crystalline fat content in the continuous butter accounts for it being harder than conventional butter.

Mulder (1953) stated that step-wise cooling reduces the tendency for mixed crystal formation and the total quantity of crystalline or solid butterfat in cream. Precrystallization of the butterfat concentrate in the laboratory continuous butter making machine apparently removes the influence of high melting point glycerides in the formation of mixed crystals and consequently, lowers the final solid butterfat content of the butter to produce a softer product (McKnight & Wood, 1962).

The real area of contact between any two macroscopically smooth surfaces is small compared with the nominal area. The former area is within limits nearly proportional to the load which presses the two surfaces together. According to Bowden & Tabor (1954), the load dependence of the real area of contact is attributed to the presence on the surfaces of numerous asperites of microscopic size. Therefore, the real area of contact would depend on the plastic deformability of the asperites. In the hesion experiments, the surfaces involved were stainless steel and butter. The former is hard and highly elastic and the latter relatively soft and plastic. When the two surfaces are pressed together, deformation of the asperites takes place on the butter surface. The softer the butter, the greater will be the real area of contact, because butter is more deformable when it is soft. Since the greater the real area of contact, the higher the formation of adhesive bonds, consequently, the force required to detach the adherend from the softer butter should be greater.

Hesion measurements made on commercial samples of conventional and continuously made butters showed consistently higher hesion values in the conventional butters. When some of these butters were subjected to homogenization, the results showed a significant increase in the hesion values. These results indicate that the structure of the butter was partly responsible for the difference in hesion values. In comparing the hardness of conventional and continuously made butters, de Man and Wood (1958c) pointed out that butter consists of primary and secondary structures. They showed that the hardness curves of printed butter were always below those of non-printed butter, indicating that part of the hardness change was irreversible: apparently a change in the primary structure was involved. The homogenization treatment is more severe than the treatment butter undergoes in a printing machine, consequently, it is quite possible that a change in structure took place.

Reworking of the conventional butter produced a very soft product. It is quite possible that because of the high temperature of the butter, a large quantity of the fat was in a liquid state. When the butter was put into the cold room at 40°F to set, crystallization took place. However, this crystallization was quite slow, resulting in the formation of large crystals which caused the butter to return to its original hardness value. As such, the hesion reading after 10 minutes of reworking should have been practically the same as the value before reworking. This is not so and could

possibly be attributed to the fact that there was a reduction in the gas content which contributed to the butter having more cohesive strength than before reworking. de Man and Wood (1959) have shown that in commercial printing machines, the gas content of butter is drastically lowered.

Generally, in the continuous butters, there was an increase in hesion values as the hardness values decreased and vice versa. The oiling-off percentages decreased after 10 minutes of reworking, but on further reworking, there was a small increase in oiling-off in the non-precrystallized butter, while no significant change was apparent in the precrystallized butter. These results appear to parallel the hardness values and indicate that both the structure and the composition of the butterfat (both the liquid and crystalline components) were changed during the reworking process.

The hesion values of the three types of butter made from the same butterfat source present further evidence that the crystal structure influenced the hesion values. The hardness values of these butters indicate that the non-precrystallized continuously made butter was hardest, followed by the precrystallized continuously made butter, with the conventional butter being softest. The hesion values parallel these hardness values.

Influence of Gas Content on Hesion Values.

It is evident from Figures 22, 23 and 24 that gas content was of significant importance on hesion values. With a small increase in gas content, there was an increase in hesion, but with

increasing gas content, there was a sharp drop in hesion values. This could possibly be explained by the fact that the small increase in gas content was enough to make the butter softer and improve the contact at the butter/adherend interface, but not enough to cause a weakening in the cohesive strength of the butter. At the higher gas contents, although the butter was softer and the contact between adherend and butter surface was greater, the hesion values decreased rapidly. This is explained by the fact that with high gas content, the cohesive strength of the butter was so weakened that a large portion of the butter remained attached to the adherend when detachment occurred. Becuase high hesion values occur when both the adhesive and cohesive strength of the butter are great, a weakening of the cohesive strength shows up in lower hesion values. This, however, does not mean that the adhesive strength of the butter is changed. Therefore, the observation which de Man and Wood (1958b) made when they said that stickiness became apparent in the continuous butter as gas content was increased, related, not to an increase in the adhesive property of the butter, but, as Claassens (1959c) explained, to a reduction in the cohesivity of its structure, which, in turn, enhanced its tendency to remain in contact with solid surfaces.

The results of this investigation indicated that the crystal structure was responsible for the adhesive property of butter and the gas content influenced the cohesive property. It would appear, then, that both the crystal structure and the gas content play an important

part in the "stickiness" defect of butter as the term is used in the butter industry, to refer to that property of butter to remain attached to solid surfaces.

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